MORE THAN BONES

An investigation of life, death and diet in later prehistoric Slovenia and Croatia

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Abstract

The East Alpine region formed an important crossroads in later prehistoric Europe, through which ideas, people and objects flowed. This was particularly the case during the Late Bronze Age/ Early Iron Age, when an increasingly competitive society was evolving, with the formation of more complex social structures and the rise of 'elites'. This has been evidenced in a shift in burial customs, from Urnfield-type cremation burial to the construction of tumuli and the adoption of elaborate inhumation burial.

This multidisciplinary, multi-scalar approach to the analysis of human remains aims to explore the evolving structure, homogeneity and heterogeneity of communities inhabiting central and eastern Slovenia, and north-eastern Croatia, during the Late Bronze Age and Early Iron Age. The application of multiple methods, including the osteological analysis of cremated and non-cremated human remains, radiocarbon dating, stable isotope analysis (carbon, nitrogen, oxygen and strontium) and aDNA analysis has facilitated the exploration and interpretation of later prehistoric social structure and lifestyle. The use of carbon (from enamel carbonate and collagen) and nitrogen stable isotope analysis has highlighted important dietary distinctions between communities inhabiting this region and previous studies from elsewhere in contemporary Europe – specifically a high dependence on millet as a staple crop. This has been evidenced by $\delta^{13}C$ values of between -17‰ and -15.3‰ from bone collagen. $\delta^{15}N$ values of between 7.6‰ and 9.1‰ support this interpretation as they do not indicate the consumption of marine protein. Increased $\delta^{15}N$ values of up to 13.5‰ from deciduous dentine have been interpreted as the influence of dietary and metabolic conditions, particularly in the presentation of an Infant exhibited palaeopathological evidence of severe metabolic disease. Complementary isotopic methods, including oxygen isotope ratios and enamel carbonate

carbon, have also highlighted heterogeneity in childhood diet, reflecting the transition from a high lipid diet of breastmilk, to a diet of carbohydrates, indicative of weaning.

In addition to these findings, the application of radiocarbon dating on cremated and nio-cremated human bone has expanded the current understanding of mortuary practices in this study area. Inhumation burial, previously thought synomemous with the Iron Age, has been now been identified throughout the Bronze Age at the cemetery of Obrežje.

The application of this multi-scalar approach to combining and interpreting these data sets has allowed for the investigation of individual biographies, as well as regional trends. This research illustrates the advantages of bringing together multiple lines of evidence for the creation of informed interpretations regarding the life, death and diet of prehistoric peoples of the East Alpine region, and beyond.

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Chapter 1 : Introduction

1.1 Aims and objectives

This doctoral research has been undertaken as part of a larger project: Encounters and Transformations in Iron Age Europe (ENTRANS). The ENTRANS Project, funded by HERA and the European Commission and running from 2013-2016, was a collaboration between the Universities of Bradford, Zagreb and Ljubljana, and the Institute for the Protection of Cultural Heritage of Slovenia, with Affiliate Partners including the Archaeological Museum of Zagreb, the National Museum of Slovenia, the City Museum of Ljubljana, the Dolenjska Museum, the Regional Museum of Maribor, the Institute for Archaeology in Zagreb, the Centre for Prehistoric Research in Croatia, and the University of Cork. The ENTRANS project aimed to explore themes of personhood, social structure and identity in the East Alpine region during the Late Bronze Age and Early Iron Age transition (Armit et al. 2014; Armit et al. 2016).

The East Alpine region includes areas of Northern Italy, Slovenia, Croatia and Austria. The north Balkans (Slovenia and northern Croatia) in particular functioned as a key gateway between east and west Europe, across the Alps, which otherwise formed a significant barrier (Armit et al. 2014). Through this gateway, settlements located on strategic points along complex networks allowed for the fluid movement of trade, migrants, linguistic forms, cultural values, and social and religious ideas (Armit et al. 2016; Potrebica and Mokos 2016). These cultural encounters would have characterised this region for much of prehistory, particularly during the Iron Age, a time of notable cultural transformation (Armit et al. 2014; Armit et al. 2016).

In the past, scholars have approached the study of Iron Age Europe as processes of “Hellenisation”, “Romanisation”, or the “civilising” of “Barbarian” societies (Armit et al. 2014). This attitude to the investigation of Iron Age Europe has neglected the consideration of other forms of cultural identity and societies beyond the control of, for example, Rome or Greece. Rather than exploring these communities as either pre/post “civilisation”, the ENTRANS project aimed to "…examine the nature and impact of cultural encounters on the construction and negotiation of identities in this area in the Early Iron Age" (Armit et al. 2014) In this way, the people inhabiting the East Alpine region could be investigated within their own context, rather than as "others" in comparison to "civilised" urban societies. To do this, the ENTRANS project aimed to examine the impact of cultural encounters through a multi-scalar methodology, investigating the local and individual scales, as well as kinship and lineage groups within the context of the region and their networks (Armit et al. 2014; Armit et al. 2016; Büster et al. 2016; Mason and Mlekuž 2016; Nicholls and Buckberry 2016; Nicholls and Koon 2016; Potrebica and Mokos 2016).

The ENTRANS project was designed to engage with the theme of Identity as a multi-faceted and fluid construct, forming and reforming in a highly dynamic environment (Armit et al. 2014; Armit et al. 2016). These evolving cultural identities were negotiated via a number of mediums, three of which were chosen by the project for investigation. These overarching themes included Art, Landscape and Mortuary Practice. The theme of Art was approached through a programme of digitisation and 3D scanning, which contributed to the exploration of techniques and iconography used during the Iron Age. (Armit et al. 2014; Büster et al. 2016) Developing funerary, domestic and economic landscapes were investigated via LIDAR mapping and geophysical survey to reveal potential networks and route-ways (Armit et al. 2014). Finally, Mortuary Practice was addressed with the use of targeted excavations and further geophysical survey, as well as extensive osteological and stable isotope analysis, which is the focus of this thesis (Armit et al. 2014; Nicholls and Buckberry 2016; Nicholls and Koon 2016).

The project team was divided into smaller research groups, who would focus on a specific theme with the aim of intertwining results and interpretations throughout the project to create informed, multidisciplinary conclusions. This research approach has shaped the present thesis, as complementary information such as detailed archaeological context (artefacts, surveys, and excavations) was the focus of other project members. For this reason, information regarding the specific individuals and cemetery groups included in the present research has been addressed, but the main archaeological discussion shall be contributed to final outputs and publications in collaboration with other project partners and principal investigators (Armit et al. 2016; Mason and Mlekuž 2016; Nicholls and Buckberry 2016; Nicholls and Koon 2016; Potrebica and Mokos 2016). The current work, therefore, represents a specific part of a larger whole.

The work presented here focusses upon the theme 'Death and the Body' via the analysis of human remains and funerary contexts from across modern-day Slovenia and northern Croatia (see Figure 1.1). Skeletal remains (cremated and non-cremated) from cemetery contexts have been investigated through the collection of osteological and isotopic data. Utilising a multidisciplinary and multi-scalar approach, the combination of these data sets has been used to explore how expressions of identity and approaches to the dead differed geographically and evolved over time.

The project has the following aims:

1) To develop an understanding of the structure and homogeneity/heterogeneity of communities inhabiting the East Alpine region during the Late Bronze Age and Early Iron Age, as reflected in the funerary record.

2) To explore how the expression of identity (e.g. gender, age, status) was reflected through mortuary practice and diet.

3) To explore how a multidisciplinary and multi-scalar approach can assist in informing our understanding of broader themes of identity and personhood in the East Alpine region during the Late Bronze Age/Early Iron Age transition.

These aims shall be addressed through the following objectives:

1) To carry out osteological analysis for age estimation and sex assessment on both cremated and non-cremated human remains.

2) To collect evidence of palaeopathology through osteological analysis and consider how this may be indicative of health in prehistory.

3) To investigate health and diet through carbon and nitrogen stable isotope analyses on bones (human and animal) and teeth.

4) To investigate the geographical origins of individuals through strontium and oxygen isotopic analyses to tooth enamel.

5) To produce informed interpretations regarding how themes of identity and identity expression can be approached through the amalgamation of multiple data sets, including osteological analysis, stable isotope analysis (carbon, nitrogen, oxygen and strontium), radiocarbon dating and aDNA analysis.

Prior to this project, there was limited osteological and isotopic data available for this study area and time period (Murray and Schoeninger 1988; Thomas 2011; Lightfoot et al. 2012; Črešnar and Thomas 2013; Lightfoot et al. 2014b). This research forms the first in-depth and multidisciplinary investigation of human remains, dating to the Late Bronze Age and Early Iron Age from central and eastern Slovenia and northeast Croatia.

Figure 1.1. Map of project study area. Cemeteries are located in central and eastern Slovenia and northeastern Croatia. Map supplied by R Kershaw.

1.2 An introduction to the funerary archaeology of Slovenia and Croatia during the Late Bronze Age and Early Iron Age

1.2.1 The Late Bronze Age

The Late Bronze Age in modern-day Slovenia and northern Croatia, as with much of the rest of Central and Western Europe, Scandinavia and parts of the Mediterranean, was characterised by a largely uniform burial rite (Harding 2000: 111-114). This consisted of the cremation of the dead and subsequent deposition of funerary urns in large communal cemeteries, which have been labelled 'Urnfields'. An example of an Urnfield type grave from Kapiteljska njive, Novo mesto, Slovenia is shown in Figure 1.2. The Urnfield period, which derives its name from these distinctive cemeteries, is thought to have spanned the 14th to the 9th centuries BC (Teržan 1999; Dzięgielewski et al. 2010).

Figure 1.2. Pottery urn in situ. Grave 33 KŽG, Kapiteljska njiva, Novo mesto (9th – 8th century BC). Source: Križ (2009: 75)

For the most part, Urnfield-type graves from the study area have been split into three categories based on the presence or absence of grave goods. These include graves without grave goods, graves with pottery only, and graves with bronze artefacts (Teržan 1999). In addition to pottery, grave goods associated with female graves consist of occasional glass beads (Figure 1.9) and circlet-shaped bronze jewellery. Bronze artefacts in male graves are primarily dress pins and occasionally razors (Figures 1.3 and 1.4). In the later phases of the Urnfield period, weapons, including bronze spearheads, axes and arrowheads, were infrequently deposited in male graves, with exceptional examples known from the cemeteries of Mestne njiva (Novo mesto, Dolenjska) and Kapiteljska njiva (Novo mesto, Dolenjska) (Križ et al. 2009: 71-81; Črešnar 2010: 82;). It has been suggested that the 'coded' occurrence of specific sets of objects in graves, notably ring jewellery (bracelets, anklets etc.), is related to a more elongated and defined female social hierarchy than that of the male sphere (Teržan 1999). Comparatively, male grave goods do not appear to reflect social hierarchy to any great extent, and it may have been less important for male social status or position to be exhibited in the final grave deposit through the use of objects during this time (Teržan 1999).

As the cremation rite is an extended funerary practice with numerous stages, male identity or status may have been displayed at a time prior to the final deposition of remains (Williams 2004; Brück 2009). For example, metal objects (particularly items of personal adornment) that were burned with the body have been identified in cremated bone deposits. This suggests that the deceased was dressed in a similar way to inhumed individuals, with the body perhaps laid out in a manner representing certain constituents of the individual's social persona on the pyre (Williams 2004). There is the probability that not all of these objects were subsequently selected for deposition, or that they were destroyed by the fire (McKinley 1994b; Brück 2009).

Figure 1.3. Bronze dress pins. Various graves, Mestne njive, Novo mesto (9th – 10th century). Source: Križ et al. (2009: 64).

Figure 1.4. Bronze razor. Grave 384A, Mestne njive, Novo mesto (9th century BC). Source: Križ et al. (2009: 74).

1.2.2 The Early Iron Age

The transition to the Iron Age was accompanied by a significant change in funerary practice across modern-day Slovenia. During this time, the creation of Urnfield cemeteries ceased, though some locations, for example, Kapiteljska njiva, continued to be used as cemetery sites. It was also at this time that inhumation graves and the construction of earthen mounds were introduced. These mounds could contain both cremated (usually in the earlier phases) and inhumed (particularly in the Dolenjska region) remains and were, in many cases, associated with a comparatively larger variety of grave goods (Križ et al. 2009: 108-119; Frie 2012). It has been argued that this increase in the variety and quantity of grave goods corresponds with an increased level of social stratification (Mason 1996: 78-85; Dular and Tecco-Hvala 2007: 237-246; Križ et al. 2009: 108-121).

Contemporaneously in northern Croatia, Urnfield-type burials appear to persist into the Iron Age, with continuity visible in the type and pattern of grave goods deposited (Dizdar 2009). In the 9th and 8th centuries BC, in a similar fashion to eastern Slovenia during the Late Urnfield phases, an increasing number of pottery and metal objects are included in northern Croatian burial assemblages – this has similarly been argued to suggest the emergence of a more stratified society containing wealthier individuals (Dizdar 2013; Teržan and Črešnar 2014). It is also during this time that inhumation burials appear in northern Croatia, which is thought to be connected with outside influences from the south and east (Dizdar 2013).

The positioning of tumuli within cemeteries, and subsequently the graves within the tumuli themselves, has been argued to indicate a founding burial and subsequent descent group (Mason 1996: 78-85, 122-125; Dular and Tecco-Hvala 2007: 237-238). In the Dolenjska region, the earliest tumuli contained a primary grave, which was frequently positioned in the centre, with secondary graves subsequently added over time. In the same region, the design of the tumuli changed in the Hallstatt D period, where graves were constructed in concentric circles, commonly without a central grave (Mason 1996: 78-85; Križ 2012). These tumuli have also been interpreted as representing “corporate descent groups”, and could have been expanded to allow for a greater number of burials (Mason 1996: 79).

In addition to tumulus cemeteries, the Iron Age funerary record is also represented by flat cemeteries and occasionally a mix of both tumulus and flat cemeteries (Dular and Tecco-Hvala 2007: 129-130). These differ from the earlier, flat Urnfield cemeteries from the Late Bronze Age, as they contain both cremation and inhumation deposits with an array of grave goods comparable to those deposited in tumulus-only cemeteries (Dular and Tecco-Hvala 2007: 129-131). This duality of funerary rite can be identified as a change in practice through time in cemeteries such as Kapiteljska njiva. At this site, the construction of Urnfield-type graves is replaced by burial under tumuli in the Early Iron Age, followed by a further period of cremation burial in flat areas (Dular and Tecco-Hvala 2007: 129-131). This pattern of cemetery development has also been identified at cemeteries including Slepšek (Mokronog, Dolenjska) and Beli Grič (Mokronog, Dolenjska) (Dular and Tecco-Hvala 2007: 129-131).

Similar, but not identical, shifts in funerary rite can be identified elsewhere in Europe (e.g. France, Germany and the Netherlands), and occur alongside high levels of continuity in other aspects of everyday life (Fokkens 2005). In these areas, this sudden change in funerary practice has been linked to abrupt transformations in the economy and social structure, rather than large-scale immigration (Fokkens 2005). In the areas included as part of the ENTRANS Project, it has been argued that the development of a competitive iron-working economy led to increased social stratification and wealth (Frie 2012; Mason 2013). This is reflected in the burial record, with the introduction of valuable items, exotic grave goods and weapons (Wells 2007; Križ et al. 2009: 117-121).

The introduction of more elaborate grave goods occurs in association with the creation of fortified hillfort settlements, with funerary assemblages suggesting the emergence of a male ‘warrior’ elite class (Mason 2009; Mason 2013; Potrebica 2016). It has been argued that the wealthiest of these elites were also accompanied in the grave by defensive attire such as armour, helmets, shields and belt fittings, such as those shown in Figures 1.5 and 1.6 (Križ et al. 2009: 117-121). Images (belonging to the tradition known as situla art) on vessels (Figure 1.7), belt plates and occasionally on horse riding equipment, have also been found in these graves (Križ et al. 2009: 117-121). Feasting and drinking sets (Figure 1.8) are also a prominent feature of these burials and were likely seen as status markers, linking these individuals with ceremonial activities where their power could be publicly displayed and maintained (Arnold 1999).

Figure 1.5. Left: Bronze Greek Helmet, Grave VII/19 Kapiteljska njiva, Novo mesto (6th-5th century BC). Source: Križ et al. (2009): 124; Right: assorted iron objects from various graves, Kapiteljska njiva. Source: Križ et al. (2009: 104)

Figure 1.6. Curved iron sword – machaira in scabbard. Grave I/16, Kapiteljska njiva, Novo mesto (8th – 7th century BC). Source: Križ et al. (2009: 118)

Grave good assemblages suggest that Early Iron Age tumuli contained the graves of both sexes and all age categories (Mason 1996: 78-85; Frie 2012). Extremely wealthy female burials are comparatively rare in relation to males and have thus far primarily been found close to large settlement centres, such as Preloge near Magdalenska gora, Griže near Stična, and Znančeve njive near Novo mesto (Dular and Tecco-Hvala 2007: 245-246). It is rare to find females occupying the central grave of a tumulus, though examples have been reported from Kapiteljska njiva, Sajevce (Kostanjevica na Krki, Posavje) and Libna (Krško, Posavje) (Dular and Tecco-Hvala 2007: 245-246). Two elite female graves from Črnomelj dating to the Hallstatt C period were furnished with bronze arm rings, neck rings, ankle rings, fibulae and two gold diadem sets (Mason 1996: 65).

Figure 1.7. Bronze figurally decorated situla. Grave IV/3, Kandija, Novo mesto (4th century BC) Source: Križ et al. (2009: 130)

Figure 1.8. Pottery vessels in situ. Grave I/33, Kapiteljska njiva, Novo mesto. Source Križ et al. (2013: 52)

Figure 1.9. Left: Glass and amber beads. Various graves, Kapiteljska njiva, Novo mesto (7th – 4th centuary). Source: Križ (2009): 40; Right: Amber bead necklace. Grave V/35, Kapiteljska njiva, Novo mesto (5th – 4th century BC). Source: Križ (2012: 105)

Several of these rich female graves also contained objects that have been associated with a ritualistic or religious class of women. These include ceramic and bronze vessels with animal head decoration, bronze sceptres, and glass and bronze items interpreted as amulets (Križ et al. 2009: 121). It has been debated elsewhere as to whether these classes of 'ritual' artefacts are related to simply a passive group of religious experts, with no other social function. An example of this debate was put forward by Knüsel (2002), who has argued in the case of the famous Vix burial, that specialists of this nature could have had influence outside the sphere of religion, also having authority in aspects of political and economic divisions. In these aspects of society, power may have been won, maintained and displayed through specific practices of gift exchange and feasting (Arnold 1999). These events could have included ritualistic elements, which would have been presided over by specific individuals, with access to a particular class of material culture (Knüsel 2002).

Further evidence from the ENTRANS study area for the active role of women in such ceremonial events can be interpreted from the contemporary situla art, where they are depicted interacting with others (Frey 2011; Križ 2012). If this was the case, it is possible that the presence of items, such as those listed above, indicate the potential for women to hold authoritative positions in society, in addition to religious sectors.

1.3 Gender and sex

As has been discussed above, past authors have attempted to attribute a sex to an individual using the contents of their graves. This has been done in instances where skeletal remains have and have not survived. Osteological analysis of human skeletal remains has rarely been carried out within the ENTRANS study area and it has become the practice to instead assign a biological sex through the presence of specific, ‘gendered’ grave goods. This approach to the assignment of biological sex to deceased individuals is problematic. The term ‘gender’ refers to a cultural understanding of appropriate roles and functions of a particular individual (Hollimon 2011: 149). This might include sanctions or restrictions on certain spheres of society or access to specific events and assemblages of material culture (Arnold 1995). Consequently, a person’s gender attribution is a culmination of biological, social and material criteria, which are used by members of a society to identify others as male/female (or sometimes ‘other’). This ascription can change over time and does not necessarily match the attribution made at birth through the observation of a newborn's biological sex (Arnold 1995). The term “sex”, on the other hand, specifically refers to biological phenotype. Subsequently, the two terms are not interchangeable.

If therefore, the attribution of gender to past individuals is not necessarily linked to their biological sex, then the assignment of sex based on the presence of certain grave goods is questionable; especially where the skeletal material does not survive. The categorising of items into strictly male/female groups restricts the understanding of past societies to a modern, westernised perception of gender systems (Weglian 2001). This neglects the possibility of gender variation and categories that may not reflect the biological sex of the individual in question (Arnold 1995; Weglian 2001; Hollimon 2011: 149).

The analysis of human remains as part of the current research is, therefore, important, as this will allow for the comparison of osteologically derived evidence of age and sex with previous assumptions of the funerary record, based on the analysis of grave goods.

1.4 Evidence of prehistoric diet

The individuals included in this study belonged to settled, agricultural communities and thus their diet probably consisted of domesticated plants and animals (Dular and Tecco-Hvala 2007: 206-212). To date, there has been no faunal evidence for the exploitation of marine resources (M. Črešnar and P. Mason pers. comm. 2014) and considering the distance from the sea of many of the sites it is unlikely that carbon isotope ratios will reflect such a component. Metal hooks from graves and activities depicted on situla art provide some evidence for freshwater fishing, and although no faunal evidence for fishing has been found, the possibility remains that this is due to taphonomic and recovery biases (including small sample sizes, and limited sieving and flotation) (Dular and Tecco-Hvala 2007: 213). Evidence of faunal remains obtained from large settlement centres, such as Stična and Cvinger, show a predominance of cattle, followed by caprine (sheep/ goat) and pig (Dular and Tecco-Hvala 2007: 212-213). Wild animals made up a relatively small proportion of animal remains, the most common being red deer, wild boar and roe deer (Dular and Tecco-Hvala 2007: 212-213).

The botanical material has provided evidence for a mixture of domesticated plants, including C3 cereals (barley, wheat, oats, and rye), legumes (vetch, faba bean, pea, lentils) and vegetables (cabbage, mustard, turnip and kohlrabi) (Dular and Tecco-Hvala 2007: 208-209). The charred remains of millet grains found in storage pits at Kučar, near Podzemelj and Sisak, Croatia, are evidence that this crop was being exploited by the Iron Age, if not earlier (Dular and Tecco-Hvala 2007: 207, 209, Fig. 119; Reed and Drnić 2016). Pilot stable carbon isotope data collected by the author, but also previous investigations have also indicated that millet was a significant food source in the study area by the Iron Age (Murray and Schoeninger 1988; Lightfoot et al. 2014b; Nicholls and Koon 2016). Carbon and Nitrogen Stable Isotope ratios from the current research will be used to investigate address the relative importance and spread if millet in the area.

1.4.1 Millet in Europe during prehistory

This research has a key focus on the adoption and consumption of millet in later prehistoric temperate Europe. This section of the thesis introduces the current understanding of the importance, spread, and use of millet across Iron Age Europe based on palaeobotany and isotopic evidence.

The adoption and spread of millet in prehistory have received considerable attention in recent years (Hunt et al. 2011; Lightfoot et al. 2013; Lightfoot et al. 2014b; Moreno-Larrazabal et al. 2015; Knipper et al. 2016; Miller et al. 2016; Murphy 2016). Millet was probably originally domesticated in the Yellow Valley in north China and subsequently transported and adopted via pre-existing trade routes (Lu et al. 2009; Liu et al. 2012; Miller et al. 2016; Valamoti 2016). This is still contested in the literature and recent genetic evidence has suggested that the origin of the domesticated species is a complex topic (Hunt et al. 2011; Miller et al. 2016; Valamoti 2016).

Millet grains have been identified in eastern and central Europe as early as the mid-7th (Foxtail millet/ *Setaria italica*) and mid-9th-millennium cal BC (Broomcorn millet/ *Panicum miliaceum*) (Moreno-Larrazabal et al. 2015; Motuzaite-Matuzeviciute et al. 2016). Millet species have been found in sizeable quantities in Europe by the 5th millennium BC and is recognised a minor crop in many areas of Europe by the Iron Age (Moreno-Larrazabal et al. 2015; Reed and Drnić 2016; Valamoti 2016).

It has been argued that this cereal was utilised as a supplementary or famine crop, animal fodder, or for consumption in marginal areas due to its ability to grow in difficult conditions (Killgrove and Tykot 2013; Moreno-Larrazabal et al. 2015; Murphy 2016; Reed and Drnić 2016). This assumption suggests that other cereals, such as wheat, were favoured above millet and if possible would be cultivated preferentially in most parts of prehistoric Europe (Vika 2011; Murphy 2016; Reed and Drnić 2016).

The socio-economic value of millet cultivation and consumption has been investigated isotopically and through archaeobotanical studies. Reed and Drnić (2016) identified a store of both Broomcorn, but more specifically Foxtail, millet from an Iron Age structure at the site of Sisak, central Croatia. They argued that this was an unusual deposit for the area and that it was unclear to what extent this crop was cultivated and for what purpose (famine or personal taste etc.). Valamoti (2016) explored the use of millet in ancient Greece, where a north-south divide could be established between those who did cultivate and store large quantities of millet (the north), and those who did not (the south). Similarly, using a combination of carbon isotope ratios from apatite and collagen, Killgrove and Tykot (2013) argued for a dietary distinction between urban and sub-urban groups of Imperial Rome, with individuals from the latter group buried outside mausolea consuming a higher quantity of millet. This suggested that people belonging to a lower socio-economic position were consuming millet as a lower status food.

The consumption of millet has also been identified isotopically in a number of studies, which have been summarised in Figure 1.10. Tafuri et al. (2009), who could identify a C4 carbon isotope signature from the bone collagen of individuals dated to the Late Bronze Age in northern Italy. Lightfoot et al. (2014) could demonstrate that Iron Age individuals from coastal Croatia also consumed C4 plants as part of their diet. Additionally, they identified a possible differentiation in status between those buried in pits, and those buried in stone-lined graves. Those buried in the pits appeared to produce a more pronounced C4 signature, indicating that millet could have been a low-status food. Alternatively, these individuals may have been buried in this way due to other social differences, unrelated to wealth or status (Lightfoot et al. 2014b). From Iron Age Slovenia, Murray and Schroninger (1988) found carbon isotope ratios from the bone collagen of Iron Age individuals buried at Magdalenska gora, reflecting a sizable C4 dietary component. This study similarly argued for the frequent consumption of millet (Murray and Schoeninger 1988). From these and other studies, it has been argued that millet may have been used to signify specific communities or social position and therefore held a symbolic significance (Killgrove and Tykot 2013; Murphy 2016; Reed and Drnić 2016).

As the consumption of millet has previously been viewed as an indicator of social status during later prehistory in Europe, combined with the evidence of millet cultivation and consumption within the ENTRANS study area, the current research investigates the prevalence of millet consumption to explore whether distinct differences can be observed between individuals or communities dating to Late Bronze Age/Early Iron Age Slovenia and north-east Croatia.

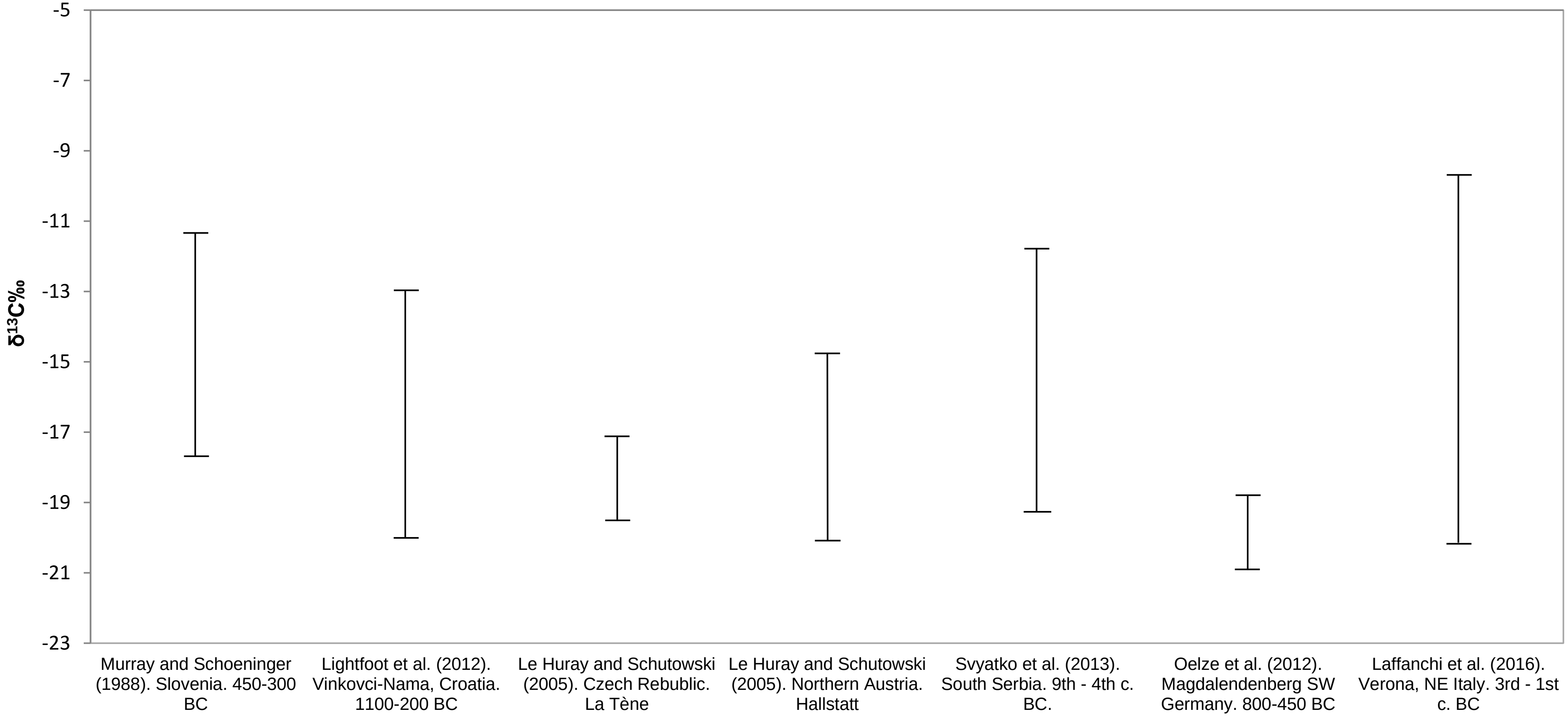


Figure 1.10 Ranges of carbon isotope ratios taken from previous investigations on palaeodiet in Iron Age Europe. For most of these studies, millet consumption has also been identified (Except for Oelze et al. 2012). However, millet eaters from the Czech Republic and Northern Austria made up less than half of their data sets.

1.5 Layout of the thesis

The chapters of this thesis are presented in the following order:

- **Chapter 2: materials.** This chapter will introduce the cemeteries that were selected for the osteological and analytical analysis of human remains. As a selection of these skeletal remains was also submitted for radiocarbon dating as part of the ENTRANS project, these dates have been included to give a chronological context to the ENTRANS assemblage of human remains. Information regarding the source of animal remains for the carbon and nitrogen isotope baseline can be found in this chapter.
- **Chapter 3: methods.** This chapter provides and discusses the osteological and isotopic methods that were selected for this project. Information regarding additional methods (aDNA, Radiocarbon dating and Strontium isotope analysis) undertaken as part of the ENTRANS project is also given.
- **Chapter 4: results of the osteological analysis of unburnt human remains.** In this chapter, the results of the osteological analysis of skeletal remains recovered from inhumation graves are presented. This includes sex assessment, age estimation and evidence of palaeopathology.
- **Chapter 5: the results of the osteological analysis of cremated human remains.** In this chapter, the results of sex assessment and age estimation of burned human remains from primarily Urnfield cemeteries, and the Early Iron Age cemetery of Kaptol (Croatia) are presented. The analysis of cremation weight, fragmentation and colour form the focus of this section of the thesis.
- **Chapter 6: the results of carbon and nitrogen isotope analysis.** The results of bulk collagen, incremental dentine and enamel carbonate analyses are presented. The carbon and nitrogen animal isotope baseline is also presented for direct comparison with human bone and dentine collagen.
- **Chapter 7:** a **case study. A carbon and nitrogen isotopic investigation of a case of probable infantile scurvy**. This chapter

provides a case study, combining both osteological and isotopic methods, to investigate the relationships between metabolic disease and stable carbon and nitrogen isotope ratios.

- **Chapter 8: the results of oxygen isotope analysis.** The results of oxygen isotope analysis using human tooth enamel carbonate are presented in relation to themes of geographical origins, residential mobility, and childhood diet.
- **Chapter 9: the results of a pilot investigation using strontium isotope analysis.** The results of strontium isotope analysis on individuals excavated from the cemeteries at Dolge njive and Križna gora are presented.
- **Chapter 10: discussion.** The discussion chapter is separated into two parts. The first, “Death and the body” primarily uses the osteological analysis to facilitate a discussion of evolving funerary rites and approaches to death across the ENTRANS study area, and beyond. The second half of this chapter, “Life and the Body” mostly addresses the isotopic data to assist in a discussion focussed on lifestyle and diet during the Late Bronze Age and Early Iron Age, and how this changed over time.
- **Chapter 11:** Conclusions and further work.

Chapter 2 : Materials

In March 2014, a team from the University of Bradford visited the Dolenjski Muzej in Novo mesto, the Institute for the Protection of Cultural Heritage of Slovenia, Novo mesto (Regional Office) and the Universities of Ljubljana and Zagreb. A preliminary rapid assessment was undertaken of 38 inhumation burials and 1076 cremation burials from several sites. These burials represented a small sample of skeletal remains from larger assemblages. These cemetery assemblages were assessed based upon the level of preservation and completeness, the availability of contextual information (such as grave location and associated grave goods), as well as the potential for good collagen preservation for isotopic analysis.

Skeletal material from the study area rarely survives the burial environments found within the ENTRANS study area and, although some skeletons selected were well preserved, most were only moderately to poorly preserved, and generally incomplete. Following the selection process, 15 sites were chosen for further study, comprising roughly 85 inhumation graves (some skeletal remains appear to have become mixed post-burial and have not been included in this total) and 320 cremation graves. Of these 320 cremation graves, 248 from three cemeteries (Ljubljana SAZU, Kapiteljska njiva and Kaptol) have been addressed in detail in this thesis as they represented the largest sample numbers and best preservation. All of the skeletal material (cremated and non-cremated), with the exception of the Križna gora assemblage, was brought to the University of Bradford for osteological and analytical analysis.

2.1 Potential and limitations of skeletal remains

2.1.1 Inhumation graves

The strategy for selecting inhumation graves was constrained by availability due to the adverse burial environment of Slovenia. Most of the skeletal remains are both poorly preserved and incomplete, which has impacted their potential for accurate and precise assessment of sex and the estimation of biological age. However, it was found that the organic component of the bone, specifically the collagen, was of a satisfactory quality for successful carbon and nitrogen stable isotope analysis for the study of palaeodiet, and radiocarbon dating. Additionally, many individuals provided sufficient dentition to carry out both oxygen and strontium isotope analysis for the investigation of geological origin and residential mobility.

2.1.2 Cremation graves

The cremated bone analysed was heavily fragmented, incomplete and frequently mixed with animal bone. For these reasons it was expected that the assessment of sex and estimation of biological age would be severely impacted. Consequently, other observations were prioritised, including bone colour, deposit weight and fragment size.

Cremated remains and isotopic analysis

It is generally accepted that the isotopic analysis of cremated bone is challenging. For the investigation of palaeodiet, the use of cremated bone is particularly problematic due to the very poor preservation of collagen. The organic component of the bone is lost at relatively low temperatures of between 300 – 500°C (Devlin and Herrmann 2015). Moreover, the cremation of the bone is a chemical process, which can result in an exchange of elements (carbon or oxygen) with the combustion atmosphere, as well as kinetic fractionation as the organic component of the bone is destroyed, but also in the bone apatite, additionally restricting the use of the mineral phase of calcined bone (Snoeck et al. 2016b). This leads to offsets in light isotope ratios in both the organic and mineral components of cremated bone, and subsequently, isotope ratios do not reflect the isotopic composition of the bone prior to cremation (Zazzo et al. 2009; Snoeck et al. 2016b). Furthermore, it is not possible to estimate the extent of these offsets. Heating experiments in the past have observed collagen isotope values to alter inconsistently in relation to being heated and, therefore, have indicated that the estimation of an original isotope ratio is incredibly difficult (Zazzo et al. 2009). It is for these reasons that cremated bone has not been included for carbon and nitrogen isotopic analysis in the current research.

Recent studies into the use of cremated bone for strontium isotope analysis have proven successful (Snoeck et al. 2015; Snoeck et al. 2016a). Changes to the crystalline structure of bone during the cremation process (over 500°c) have been shown to inhibit strontium incorporation into the crystal matrix (Zazzo et al. 2009; Snoeck et al. 2015). This reduces the chances of diagenesis and contamination due to the uptake of strontium from the burial environment. Studies have even suggested that the level of diagenesis into the bone may be less than that of tooth enamel – currently the favoured element for strontium isotope analysis (Snoeck et al. 2015). This method, however, has only been recently developed and so has not been included as part of the ENTRANS sampling strategy. The technique would, nevertheless, be an interesting line of investigation for future projects, especially as the number of cremation burials significantly exceeds the number of surviving inhumation graves within the study area.

Due to the difficulties surrounding the stable isotope analysis of cremated bone, these remains have been limited to observation-based analysis and for radiocarbon dating.

2.2 The cemetery sites

Most sites have been recorded in the form of unpublished excavation reports (Draksler 2011; Murko 2011) and consequently, contextual information is limited. The sites and number of individual inhumation and cremation graves selected for osteological analysis, and subsequently sampled for other analyses, are presented in Figure 2.1 and Table 2.1. These numbers represent the number of excavated graves, not the minimum number of individuals. Consequently, each grave may contain more than one individual. This issue is addressed further in Chapter 3.

2.2.1 Radiocarbon dating

As part of the ENTRANS project, 56 samples of cremated and non-cremated (including animal and human) bones were submitted for Radiocarbon dating at the Scottish Universities Environmental Research Centre (SUERC), Glasgow. The total results of this can be found in Appendix D, disk 1. A sample of these dates has been presented below, alongside descriptions of cemetery sites, to provide a chronological context to the skeletal material. Where possible, radiocarbon dates produced from other investigations have been included in the

Oxcal plots. These can be distinguished by their laboratory codes, as no previous radiocarbon dating was carried out by SUERC. All figures were created for the ENTRANS Project by Sam Harris (at the University of Bradford) utilising the OxCal program version 4.2.4 (Bronk Ramsey 2009; Bronk Ramsey and Lee 2013) with the terrestrial calibration curve IntCal13 (Reimer et al. 2013). As no evidence of marine diet was identified from carbon and nitrogen isotope analysis (Chapter 4), radiocarbon dates did not require correction with mixing curves (Cook et al. 2015). All radiocarbon dates are presented at the 95% confidence level.

Inhumation Graves	
Site	*Number*
Zagorje ob Savi	6
Ljubljana Congress Square	3
Dolge njive	9
Metlika/ Hrib	2
Kapiteljska njiva	2
Obrežje	5
Križna gora	40
Sv Petar Ludbreški	2
Sv Križ	4
TOTAL	**73**
Cremation graves	
Kapiteljska njiva	60
Ljubljana SAZU	167
Kaptol	21
TOTAL	**248**

Table 2.1. Numbers of cremation and inhumation graves sampled from each cemetery site for osteological analysis. Grofove njive inhumation graves have not been included in this total, as individual contexts (15) have been recorded with small finds numbers, rather than a grave or skeleton number.

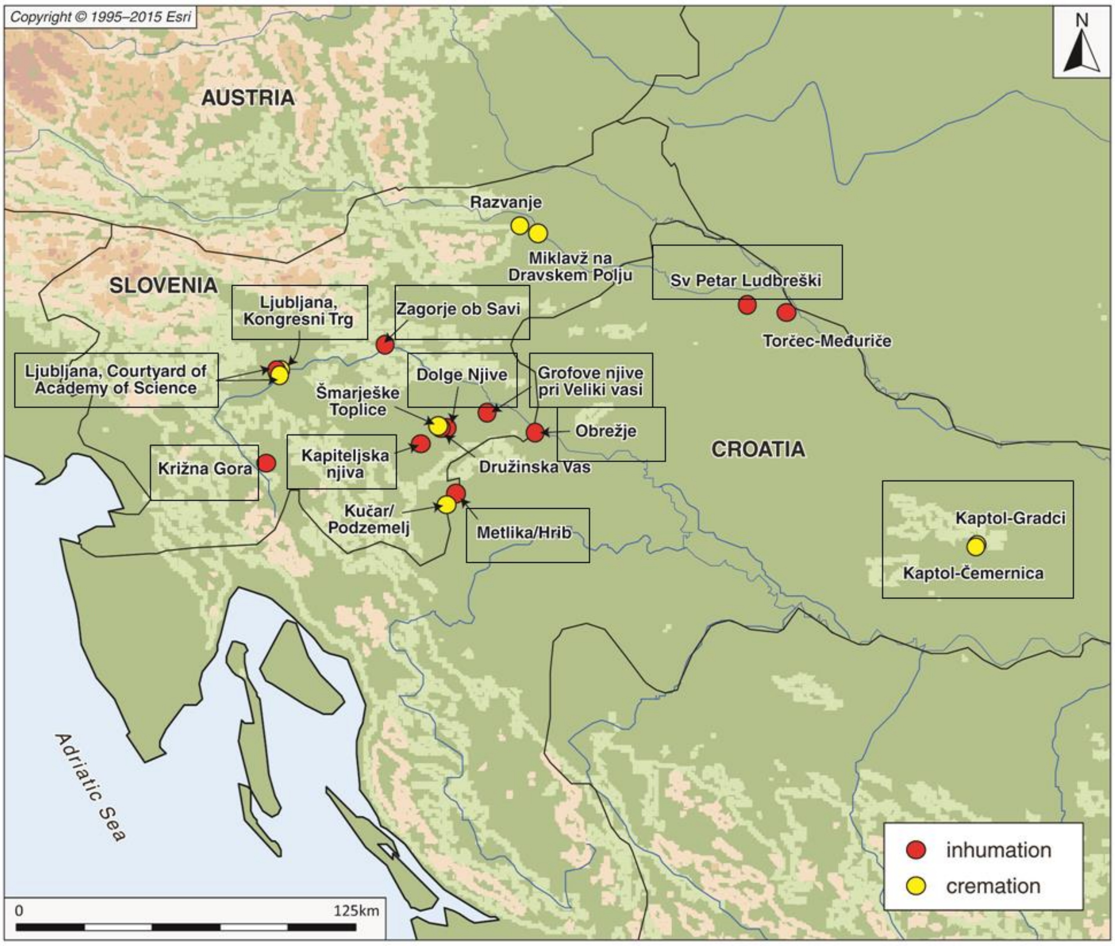


Figure 2.1. Map of project study area showing the geographical spread of cemeteries selected for analyses by the ENTRANS Project. The red circles indicate the location of inhumation cemeteries and yellow circles the location of cremation cemeteries. Labels highlighted with squares have been specifically selected for presentation in this thesis. Maps supplied by R Kershaw 2017.

Križna Gora

This site was located on a limestone karstic hill. Excavations took place in 1957, 1958 & 1959. The 1825m^2 area contained 140 cremation and inhumation burials, with an additional 13 found during trenching (Urleb et al. 1974; Teržan and Črešnar 2014). Slabs of grey limestone partly or completely covered most graves, sometimes in two layers. Most graves (Cremation and Inhumation) were at least partly lined with dolomite stones (Teržan and Črešnar 2014: 525).

This cemetery was selected for the osteological analysis of inhumed individuals, to provide context for subsequent Stable Isotopic analyses. The age estimations and sex assessments of 32 individuals were carried out by the author and Dr Hannah Koon at the University of Ljubljana. Assistance was required as there was a limited period of one week to access, select, analyse and sample the assemblage for analytical analyses. During the analysis, some issues regarding the storage and curation of the skeletal material were noted. Previous analyses of the assemblage had resulted in the separation of diagnostic elements for age and sex into separate envelopes. Consequently, there seems to have been some mixing of elements and individuals. This was made apparent where previous work reported, for example, an adult male, but the remains themselves were that of a child (Urleb et al. 1974). Discrepancies were noted on recording forms. Based on the cemetery monograph, none of the graves included in this study were originally recognised as multiple burials (Urleb et al. 1974). Where there are instances of A and B, this indicates the possibility of individuals not matching the original skeleton number.

The Križna gora skeletal assemblage forms the largest cemetery sample analysed as part of this research, providing the largest sample numbers for isotope analyses (carbon, nitrogen, enamel carbonate and oxygen). Additionally, because of the availability of well-preserved dentition, seven samples were selected for a strontium isotope pilot study. For this reason, this site is used as a key case study throughout this thesis, addressing key research themes of diet, demography and mobility. As the access to these skeletal remains was limited, they were not sampled for aDNA analysis.

Radiocarbon dates

Although Križna gora was selected as a site for more in-depth investigation, including strontium isotope analysis, fewer individuals were selected for radiocarbon dating (Table 2.2; Figure 2.2). This was primarily because the site had already produced five radiocarbon dates from earlier investigations (Teržan and Črešnar 2014). From the total number of radiocarbon dates from Križna gora, it is likely that the individuals buried here were broadly contemporaneous with those buried at Dolge njive. For this reason, the two cemetery sites have been considered broadly chronologically comparable for strontium isotope and other analyses.

Laboratory code	*Sample*	*BP*	*+/-*	*Calibrated Age Range (years BC) 95% confidence*
SUERC-69442 (GU42042)	Križna gora grave 34	2550	30	810-550
SUERC-69708 (GU42043)	Križna gora grave 59	2461	31	760-420
KIA-43422	GRAVE 36	2680	30	900-800
KIA-43423	GRAVE 78	2450	30	760-410
KIA-43424	GRAVE 100	2390	30	730-390
KIA-43425	GRAVE 103	2515	30	800-540
KIA-43426	GRAVE124	2485	30	780-480

Table 2.2. Radiocarbon dates for Križna gora (95% confidence). Radiocarbon dates produced by ENTRANS are in black. Previous radiocarbon dates are in grey. Additional radiocarbon dates sourced from Teržan and Črešnar (2014)

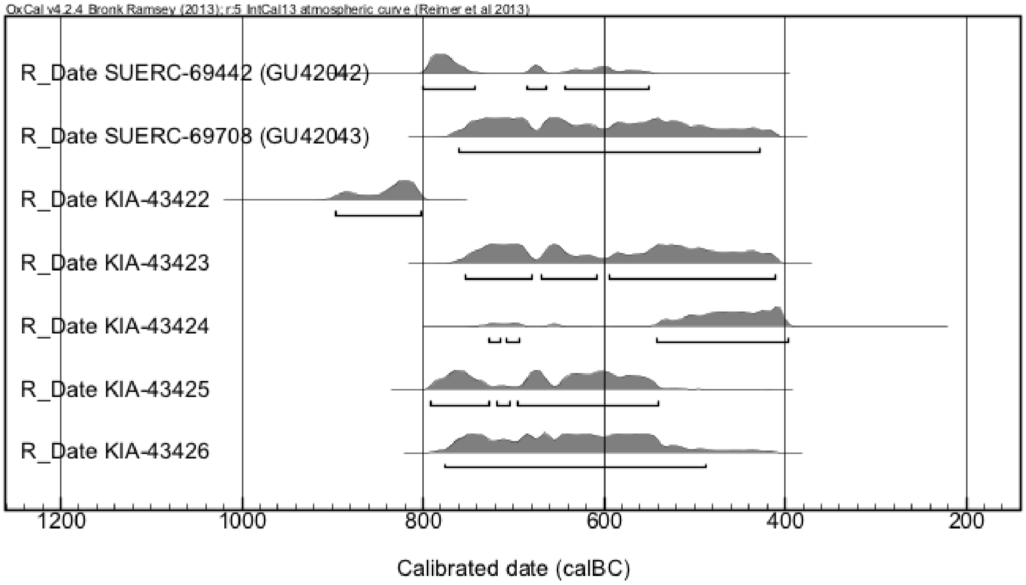


Figure 2.2. OxCal plot of radiocarbon dates for Križna gora (95% confidence). The radiocarbon dates produced by ENTRANS have the lab code "SUERC". Radiocarbon dates from previous investigations have the lab code "KIA". Additional radiocarbon dates sourced from Teržan and Črešnar (2014). Calibration curve: Reimer et al. (2013). OxCal software: Bronk Ramsey and Lee (2013). (S. Harris pers. comm. 2017).

Obrežje

The settlement for Obrežje may have been to the north-eastern side of the border crossing plateau (represented by several post-built structures, but no finds), or it could have been located on the Pleistocene terrace of the river Sava, which is north-west of the cemetery (P. Mason pers. Comm. 2017). Here, a large prehistoric complex was identified from field-walking, but no extensive excavation has taken place. Archaeological evidence has suggested this complex date to the Middle Bronze Age, and so should match the date of the earlier inhumations at Obrežje (P. Mason pers. Comm. 2017).

This cemetery (shown in Figure 2.3) is, for the most part, a large flat urnfield-type cremation cemetery dating to the Late Bronze Age (Mason 2009). The individuals included as part of the ENTRANS project consist of five skeletons found among the cremation burials. Grave goods at this site were rare, with Graves 2828 and 2544 each containing a bronze roll-headed dress-pin, while Grave 3043 a small pottery cup. This cup contained a small assemblage of human remains, which have also been examined.

Previously thought to be broadly contemporary with the rest of the cemetery, these skeletons have been individually described due to their surprising chronology, which is detailed below. Due to the poor preservation of the cremated remains, they were not selected for this investigation.

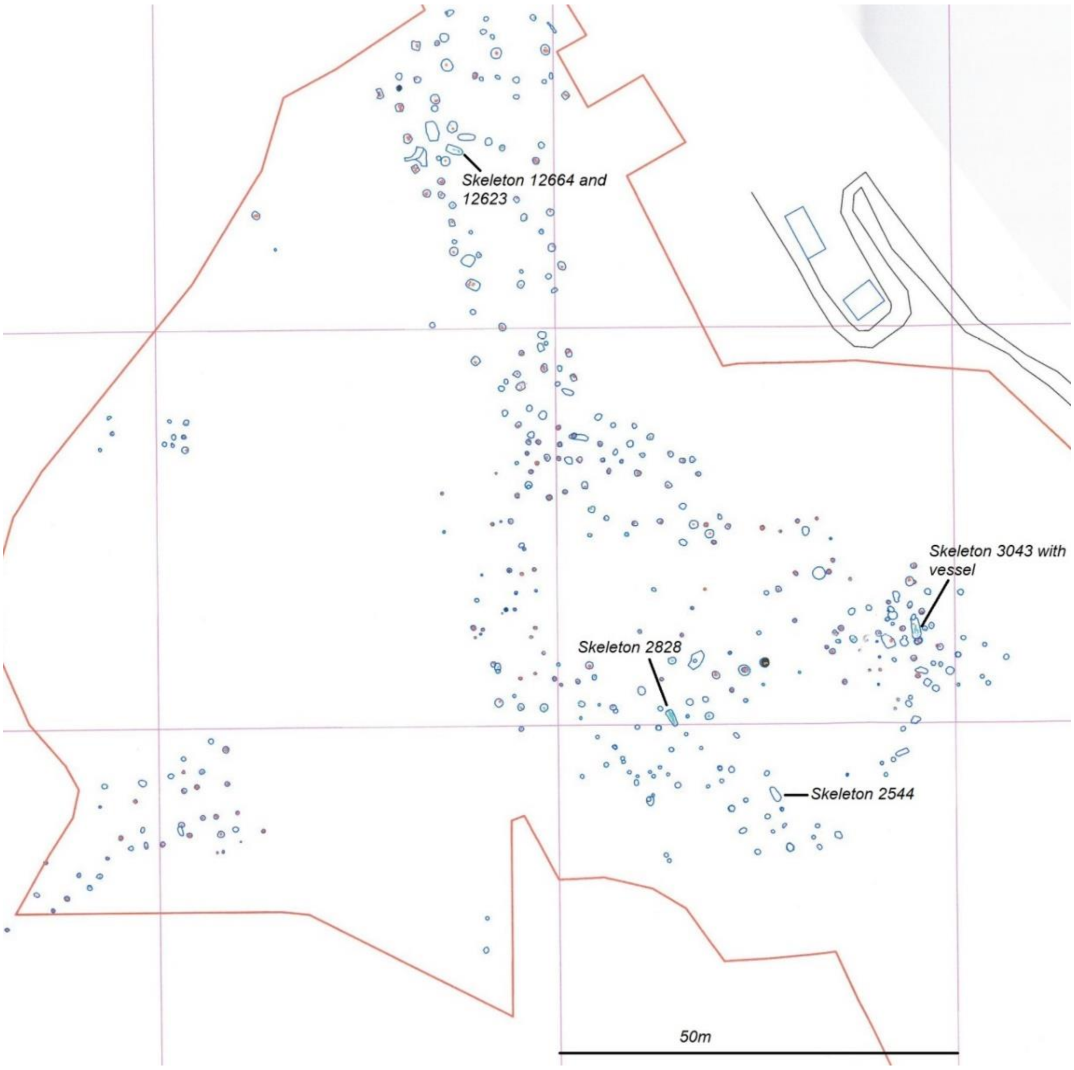


Figure 2.3. A plan of the Obrežje cemetery. Inhumation graves have been indicated to show their location within the urnfield. The skull of skeleton 12623 was found within the fill of the grave of skeleton 12664 and may have been originally part of an earlier grave. Inhumation graves appear to reference Urnfield cremation graves and vice versa, as the two grave types have not been distinguished spatially. Adapted from plan sourced from P. Mason (2017).

This cemetery was revisited over the centuries for funerary activity. This is a unique phenomenon within the ENTRANS dataset. The site of Kapiteljska njive, for example, was used continuously throughout the Urnfield period and into the Iron Age, but it does not appear to have been the same situation at Obrežje. This site is, first and foremost, an Urnfield cemetery focussing on the funerary rite of cremation. These few inhumations, with such an unexpected chronology, are therefore anomalous inclusions. For this reason, these inhumed individuals are revisited throughout the remainder of this thesis, to assess if any further information can reveal any differences between them and the rest of the ENTRANS assemblage. For example, can a C4 signal be detected in the carbon isotope ratios of Bronze Age individuals, indicating the early consumption of millet in the study area.

Radiocarbon dates

The radiocarbon dates produced from this cemetery can be found in Table 2.3 and Figure 2.4. The human remains analysed were originally thought to be broadly contemporaneous because of their location within a larger Urnfield cemetery, with which they were also supposed to be of a similar date. The scarcity of grave goods from the graves also led to complications attributing a date to these individuals.

Following the radiocarbon dating of human bone collagen, it has become apparent that there is a more complex chronology at this site than previously thought. The earliest inhumation burial has been radiocarbon dated to the Middle Bronze Age, while the latest dates to the later Iron Age. This group of inhumations, therefore, potentially spans a time of up to a thousand years. The individuals appear to fall into three groups, with the two non-adults (Grave 12623 and Grave 12664) dated to the Middle Bronze Age (c.1400-1250 BC), two individuals from the same grave cut (the vessel remains and skeleton 3043) to the Late Bronze Age (c. 1000-800 BC), and one adult male (Grave 2544) to the Iron Age (410-210 cal.BC).

The Obrežje vessel remains were a small sample of human bones found inside a ceramic cup, which had been placed at the feet of skeleton 3043. The calibrated dates provide a potential overlap of fifty years, but it is likely that the human remains found within the vessel predate the inhumation grave within which it was found. This matches the highly fragmented, incomplete, and weathered appearance of the remains from the vessel, and prompts the question of whether these were curated skeletal remains.

Laboratory code	*Sample*	*BP*	*+/-*	*Calibrated Age Range (years BC) 95% confidence*
SUERC-69438 (GU42038)	Obrežje PN 2544	2281	29	410-210
SUERC-69439 (GU42039)	Obrežje vessel remains (with skeleton 3043)	2802	29	1030-850
SUERC-69436 (GU42036)	Obrežje PN 3043	2693	29	900-800
SUERC-69437 (GU42037)	Obrežje PN 12623	3086	30	1430-1270
SUERC-69432 (GU42035)	Obrežje PN 12664	3061	30	1420-1230

Table 2.3. Radiocarbon dates for Obrežje (95% confidence); Calibration curve: Reimer et al. (2013). OxCal software: Bronk Ramsey and Lee (2013). (S. Harris pers. comm. 2017).

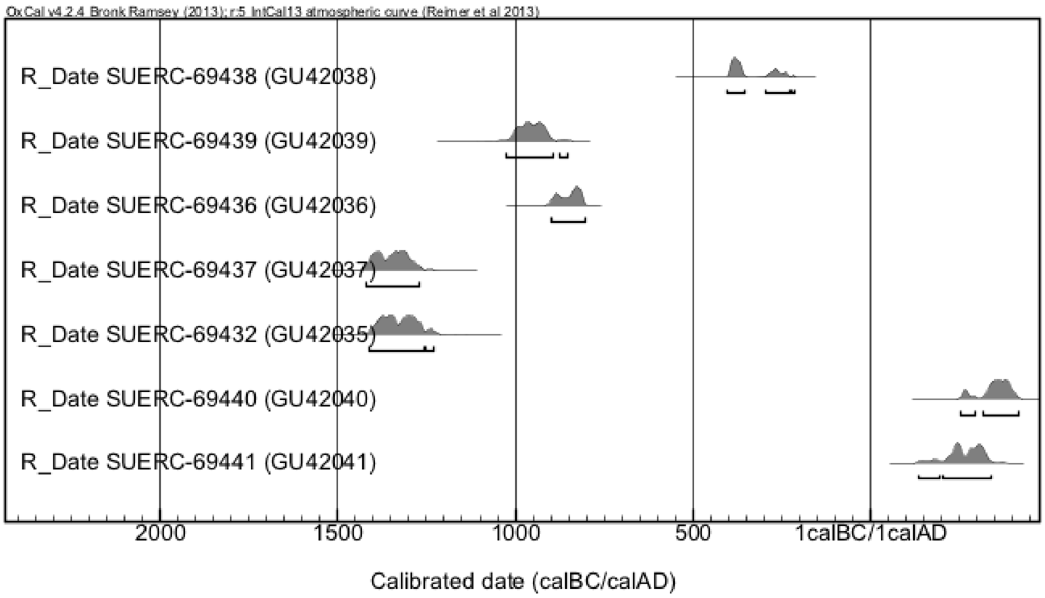


Figure 2.4 OxCal plot of radiocarbon dates for Obrežje (95% confidence). The final two dates were produced from cattle bones and are discussed in section 2.3. Calibration curve: Reimer et al. (2013). OxCal software: Bronk Ramsey and Lee (2013). (S. Harris pers. comm. 2017).

Dolge njive

The site consists of three Early Iron Age Barrows thought to have spanned a relatively short period, from Ha C1- Ha C2. The barrows reference the previously existing Late Bronze Age mortuary complex, as they were constructed upon earlier cremation platforms (Mason and Mlekuž 2016).

The nine graves from this site were selected for a more in-depth investigation because of their number and preservation of multiple skeletal elements. In addition to osteological analysis, as well as carbon, nitrogen and oxygen stable isotope analysis, these remains were selected for strontium isotope analysis. Furthermore, a greater number of individuals were submitted for radiocarbon dating (see Section 2.2).

As a key cemetery chosen for multiple investigations, this site is compared to the site of Križna gora, particularly regarding the isotopic analyses, throughout this thesis. Additionally, this site was selected for aDNA analysis because of the number of available petrous portions. This was an advantageous sampling strategy, as these individuals were buried within the same earthen mound. It was, therefore, possible to explore familial relationships within the burial monument. This was particularly interesting as, although it has long been believed that these burial mounds contained lineage groups, it had thus far not been tested.

Radiocarbon dates

A larger sample was radiocarbon dated from Dolge njive, as this cemetery was part of a more in-depth case study, including strontium isotope analysis. To compare individuals, it was useful to know how contemporaneous the graves were, especially as the overall sample size at the cemetery was so small. As illustrated in Table 2.4 and the OxCal plot for the site (Figure 2.5), all the dates overlap. The wide date ranges produced by these bone samples have probably been affected by the Hallstatt plateau in the radiocarbon calibration curve (Reimer et al. 2013). For the purposes of other analyses, these individuals have been identified as broadly comparable based upon their chronology, with the individuals buried at Dolge njive probably all dating to the Early Iron Age.

Laboratory code	*Sample*	*BP*	*+/-*	*Calibrated Age Range (years BC) 95% confidence*
SUERC-69426 (GU42028)	Dolge njive grob 7 Animal bone	2457	29	760-410
SUERC-69427 (GU42029)	Dolge njive 1775	2531	29	800-540
SUERC-69428 (GU42030)	Dolge njive 2680	2569	30	810-550
SUERC-69429 (GU42031)	Dolge njive 1781	2544	29	800-540
SUERC-69707 (GU42032)	Dolge njive 1883	2525	31	800-540
SUERC-69430 (GU42033)	Dolge njive 2900	2537	29	800-540
SUERC-69431 (GU42034)	Dolge njive 2603	2507	29	790-540

Table 2.4. Radiocarbon dates for Dolge njive (95% confidence) Calibration curve: Reimer et al. (2013). OxCal software: Bronk Ramsey and Lee (2013). (S. Harris pers. comm. 2017).

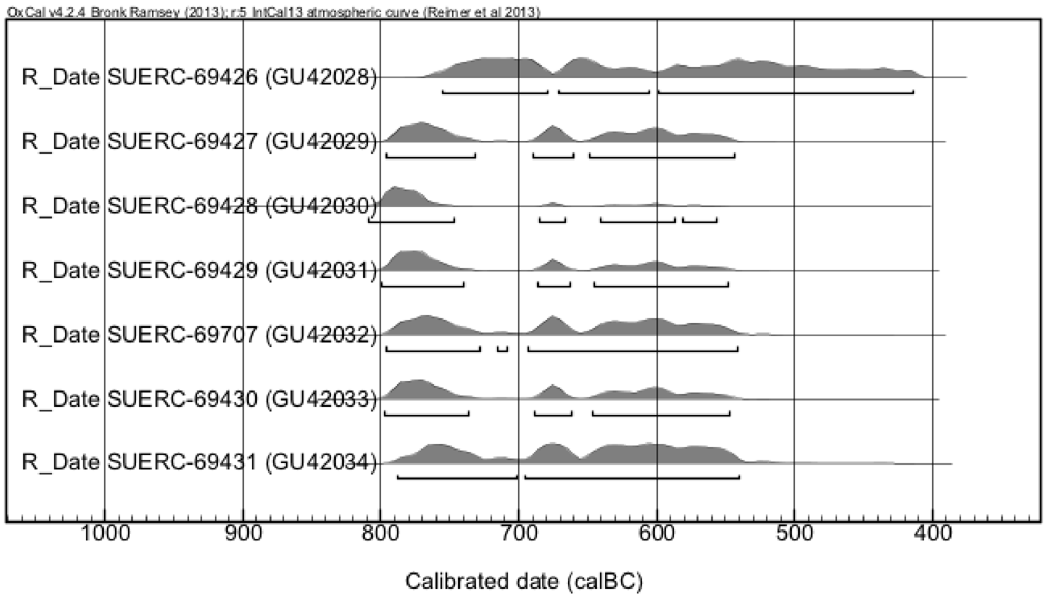


Figure 2.5. OxCal plot of radiocarbon dates for Dolge njive (95% confidence). Calibration curve: Reimer et al. (2013). OxCal software: Bronk Ramsey and Lee (2013). (S. Harris pers. comm. 2017).

Zagorje Ob Savi (Zasavje)

The excavated area of the cemetery consists of nine flat, sub-rectangular graves orientated SE–NW. These graves were lined with large dolomite stones and had stone rubble on top. Graves 4, 5 and 7 were robbed during antiquity and did not yield any skeletal remains. The grave goods recovered from the remaining graves date the site to the Early Iron Age, and subsequent radiocarbon dating as part of the ENTRANS project has verified this (see below).

The skeletons were positioned supine with their arms and legs extended. One grave (Grave 5) exhibited evidence of a wooden lining and perhaps covering.

Two infant graves (excavated by Draksler in 2011 and hereby referred to as Infant 1 and Infant 2. Codes provided upon excavation can be found in Appendix A, Disk 1) were found in very close proximity to each other. Except for their smaller size, the graves were constructed in an identical fashion to that of the adult graves.

The preservation of the skeletal material from this site was generally poor. This was probably due to the burial environment, but also because of frequent disturbance and destruction from the building of utilities in the recent past.
This site was primarily used as a sample for carbon, nitrogen and oxygen isotope analysis. This data could then be compared to other sites to assess geographical and special isotopic variability. As this assemblage also included non-adult individuals, it was also selected for incremental dentine sampling for carbon and nitrogen isotope analysis, to assess dietary and metabolic change during the lives of children who did not survive into adulthood. From this data set, a particularly interesting case study (Chapter 7) has been produced, investigating diet and metabolic disease during infancy.

Radiocarbon dates

The radiocarbon dates from this cemetery can be found in Table 2.5 and Figure 2.6. The calibrated dates correspond well with the grave goods with which the individuals were associated (pers. comm. M. Črešnar), which had already indicated that these individuals had been buried during the Early Iron Age.

Laboratory code	*Sample*	*BP*	*+/-*		*Calibrated Age Range (years BC) 95% confidence*
SUERC-69421 (GU42026)	Zagorje Infant 1	2412	29		750-400
SUERC-69422 (GU42027)	Zagorje Grob 2	2499	28		790-530

Table 2.5. Radiocarbon dates for Zagorje ob Savi (95% confidence) Calibration curve: Reimer et al. (2013). OxCal software: Bronk Ramsey and Lee (2013). (S. Harris pers. comm. 2017).

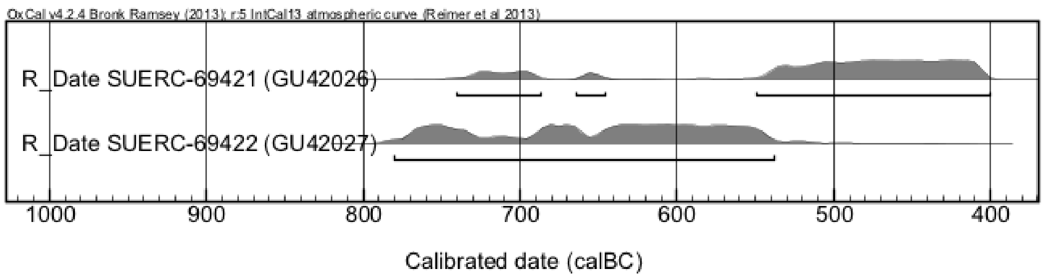


Figure 2.6. OxCal plot of radiocarbon dates from Zagorje ob Savi (95% confidence). Calibration curve: Reimer et al. (2013). OxCal software: Bronk Ramsey and Lee (2013). (S. Harris pers. comm. 2017).

Ljubljana Congress Square (Ljubljana)

The three inhumation graves included in this study were found in the vicinity of an Early Iron Age barrow, which contained cremated remains (Horvat and Novšak 2011). The individuals from this site were accompanied by both ceramic and metal grave goods (Horvat and Novšak 2011). These non-cremated individuals were sampled for carbon, nitrogen and oxygen isotope analysis to assist in the assessment of spacial isotopic variability. As non-adults were identified from this site, these individuals were also selected for incremental dentine sampling for carbon and nitrogen isotope analysis, to investigate dietary and metabolic variability in individuals who did not survive into adulthood.

42 cremation graves were originally selected for the ENTRANS project, but it was discovered later that a number of these graves probably dated to the Roman period. As this site is part of an on-going process of excavation recording, clarification was not available from site reports or records. Due to the uncertain context of many of these graves, they were discounted from further analyses.

Metlika/ Hrib

This tumulus cemetery has been radiocarbon dated to the Late Bronze Age and Early Iron Age (see below). The barrow is located on a large terrace under the hill of Veselica (Teržan and Črešnar 2014). The site was composed of six small barrows, which had later been badly damaged by agriculture and development.

Tumulus 1, where the two graves included as part of the ENTRANS project were uncovered, was in the easternmost part of the site. The mound was oval in plan and measured 24 x 21m (Teržan and Črešnar 2014). The mound had 2 layers with 82 cremations and 8 inhumation graves. Grave goods indicate the mound was founded in the Late Urnfield Period. These earliest cremations were surrounded by stones and likely a small earthen mound. The second layer dates to Early Iron Age and contained both cremation graves and the inhumation graves (Teržan and Črešnar 2014).

Due to the poor preservation of skeletal material from this site, only two individuals could be included in the ENTRANS project. The remains were of exceptionally poor preservation and were primarily sampled for isotope analyses (carbon, nitrogen and oxygen), to assist in the investigation of spatial isotopic variation at a regional level.

Kapiteljska njiva

This site represents the most extensive prehistoric cemetery found in Novo mesto to date. The site spreads across the tops and slopes of a hill overlooking the meander of the Krka River (Križ 2013; Teržan and Črešnar 2014). The cemetery is located North-West of the prehistoric hillfort settlement at Marof (Križ 2013). The cemetery was used continually from the Urnfield period into the Late Iron Age (Križ 2013). Urnfield period graves consist of flat cremation graves, Early Iron Age inhumation graves were placed under and within barrows, and Late Iron Age graves were, again, flat cremation graves (Križ 2013).

Similar to the Metlika/Hrib assemblage, the skeletal remains from this site are of very poor preservation, often entirely destroyed. For this reason, only two (from Tumulus 3) inhumed individuals could be included in this investigation, for the assessment of isotopic variation at a regional scale.

265 cremation graves dated to the Urnfield period, 60 of which survive and have been analysed as part of the ENTRANS project. The quantity of cremated material was sufficient to be used as a key case study. The remains were assessed for trends in fragment size, element representation and colouration to investigate inter and intra-cemetery variation in cremation conditions and deposition.

Grofove njive

This complex consists of an unfortified, lowland settlement site with an Early Iron Age barrow. The results of 8 previous radiocarbon dates and typology suggest that the settlement and cemetery are likely contemporaneous at roughly 500 BC (Teržan and Črešnar 2014). The probable barrow (identified because of its enclosing ditch) was located approximately 35m North-East of the settlement. Four graves containing five skeletons were uncovered and the remains of a fifth, destroyed grave (Teržan and Črešnar 2014).

The skeletal material recovered from this site was of exceptionally poor quality. Of the material analysed at Bradford, the majority arrived as part of unexcavated soil blocks. These blocks were subsequently micro-excavated and cleaned by Frankie Wildman as part of an undergraduate placement. Following micro-excavation, it was clear that very little of the skeletons (probably from four graves) had survived, and what remained was in a very fragmented and fragile state. Most of the information gathered from these individuals comes from their dentition, most of which was missing. In terms of the osteological analysis, these individuals were too damaged and incomplete to provide much data, however, in terms of stable isotope analyses, the remains proved adequate for carbon, nitrogen and oxygen isotope analysis. This data was used to support the investigation of spatial isotopic variability at a regional level, to explore the potential for geographical differences in dietary practices.

Ljubljana SAZU (Courtyard of the Slovenian Academy of Sciences and Arts)

A total of 334 flat cremation graves were recorded at this site, 177 of which were accessible for analysis in the present study. The site is one of several cremation cemeteries in the present-day city centre of Ljubljana and was likely associated with the prehistoric settlements on Castle Hill and at Tribuna (Teržan and Črešnar 2014). The oldest graves (2,277 and 278) have been attributed to Hallstatt A, i.e. the earlier phase of the Urnfield Period (Teržan and Črešnar 2014). It was reported that “male” graves (based on typologies of grave goods) were associated with bronze roof and conical-headed pins, with contemporary “female” graves containing the first Iron jewellery (Teržan and Črešnar 2014).

This cemetery forms that largest sample of cremation graves analysed in this study. Subsequently, this site forms a key focus in the analysis of cremated remains. The cremated skeletal remains were assessed for trends in fragment size, element representation and colouration. The data has been compared with that collected from Kapiteljska njiva and Kaptol to investigate inter and intra-cemetery variation in cremation conditions and deposition. From this data, the ways in which the dead were viewed and treated have been theorised.

Sv Petar Ludbreški (Podravina, northern Croatia)

Two individuals from this site were analysed; one was excavated by K. Vinski-Gasparini (from Arheološki Muzej u Zagrebu) in 1960 and the second was discovered in the periphery of the Early Iron Age settlement during an excavation led by M. Šimek from Gradski Muzej Varaždin in 1978. Unfortunately, due to the poor recording of these excavations, very little information survives regarding their contexts. However, these two individuals may have been associated with a settlement site, rather than a cemetery. Both individuals were excavated from pits and were reported to have been buried in a crouched position. They were both associated with Early Iron Age pottery, though the individual excavated in 1960 has now been radiocarbon dated to the Late Bronze Age. The male recovered in 1978 was also buried with a large grindstone (pers comm S. Kovačević).

These individuals were included as a case study because of their unusual burial and bodily treatment. Following the radiocarbon dating of Sv Petar Ludbreški 1960 to the Bronze Age (all Croatian radiocarbon dates have been combined below), carbon isotope ratios were examined to investigate the possibility of C4 plant consumption as evidence of Bronze Age millet.

Sv Križ Brdovecki (Croatia)

This site was made up of a number of flat inhumation graves in the vicinity of an Early Iron Age tumulus (pers. comm. H. Potrebica 2017). Within the tumulus was the burial of what has been described as a male princely grave. This grave consisted of a single individual, accompanied by the remains of a horse and horse-riding equipment. As such, this individual has been labelled the "Horseman". A rare form of helmet was also recovered, alongside ceramic vessels, bronze belt buckle and other bronze and Iron objects (Škoberne 2004: 161-170). This individual has been included in the present study, in addition to seven individuals buried in the surrounding flat graves.

This site was selected to investigate any potential isotopic differences that could be linked to the apparent high status of the site. This included investigations into diet through the application of carbon and nitrogen analysis, but also exploring the possibility of mobility through the use of oxygen isotope analysis. Additionally, this isotope data contributed to the corpus of data produced by other sites, which could be used to investigate spatial isotopic variability.

Kaptol-Gradci and Kaptol-Čemernica

From this cemetery, all the graves excavated to date (21 sets of cremated remains) were analysed as part of this research: 15 from Kaptol-Gradci and 6 from Kaptol-Čemernica. All the following context information was provided by Professor Hrvoje Potrebica.

The Kaptol complex consists of a fortified settlement and two necropolises: the first (southern) necropolis is on site Čemernica, and the second necropolis (and settlement) is on the site of Gradci (north from Čemernica). To differentiate between the two sites, the excavators have used two numerical systems: Roman numerals for Čemernica (i.e. I, II, III etc.) and Arabic numerals for Gradci (i.e.1, 2, 3,).

The site of Kaptol-Čemernica was excavated by the Archaeological Museum in Zagreb (1965-1971). Fourteen tumuli (I-XIV) were excavated, though some of them yielded no results and it is now known that “Tumulus XIV” is Neolithic settlement and not tumulus. The cremated remains were rarely preserved and there is little or no contextual information. Further excavations were carried out by Centre for Prehistoric Research in 2007 (Tumulus XI, also called Volarska Glavica) and in 2009 (Tumulus III). The cremated bone obtained from these graves was often in small quantities and highly fragmented.

17 tumuli (1-17) at the site of Kaptol-Gradci were excavated by the University of Zagreb, Department of Archaeology, and Centre for Prehistoric Research from 2001 to the present day. No obvious grave was identified under Tumulus 4, but all the others contained some cremated bone, though this was sometimes very fragmented and of low weight.

This is the only cremated skeletal material analysed that has been dated to the Iron Age. The individuals buried here are believed to have been of high status because of the size of the monuments, and the quantity and type of grave goods associated (weaponry, items or personal adornment, armour, and drinking and feasting equipment). These remains were selected to investigate the demographics of individuals buried at this site, to engage with theories of earned or inherited status. Another key objective was to compare the cremated remains from this cemetery with that of Bronze Age, urnfield cemeteries (Ljubljana SAZU and Kapiteljska njiva), to explore potential similarities and differences between them. This included aspects such as fragmentation, element representation and colouration. Subsequently, from these comparisons, to interpret whether there was any evidence of changes in cremation practice and pyre technology between the two periods.

Radiocarbon dates

<u>Kaptol, Kagocac, Sv Križ Brdovecki and Sv Petar Ludbreški (Croatia dates)</u>

As demonstrated in Figure 2.7 (and Table 2.6), the individuals buried at Kaptol fall on the Hallstatt plateau of the calibration curve and have, therefore, provided relatively wide date ranges of between 750-550 cal. BC (Reimer et al. 2013).

Radiocarbon dates from Kagovac and the princely grave from Sv Križ Brdovecki are also, as expected, laying on the Hallstatt plateau between the eight to sixth centuries cal. BC, and probably around the fifth century BC respectively. Sv Petar Ludbreški 1960, on the other hand, had a more surprising radiocarbon date in tenth century BC. This was earlier than expected, as this individual was thought to also have dated to the Early Iron Age. Another single grave from Croatia (Torčec), originally thought to be broadly contemporaneous with that of Sv Petar Ludbreški, was radiocarbon dated to the medieval period and subsequently excluded from further discussions.

Laboratory code	**Sample**	**BP**	**+/-**	**Calibrated Age Range (years BC) 95% confidence**
SUERC-69678 (GU42002)	T6 Mammal	2524	30	800-540
SUERS-69679 (GU42003)	T7 Mammal	2487	30	780-490
SUERC-69680 (GU42004)	T9 Mammal	2572	30	810-560
SUERC-69681 (GU42005)	T10 Mammal	2488	30	790-490
SUERC-69685 (GU42006)	T11 Mammal	2517	30	800-540
SUERC-69686 (GU42007)	T12 Mammal	2485	30	780-480
SUERC-69687 (GU42008)	T14 Mammal	2502	30	790-530
SUERC-69688 (GU42009)	T16 Mammal	2476	30	780-430
SUERC-69689 (GU42010)	T II GROB 2	2467	30	770-430
SUERC-69690 (GU42011)	T III Mammal	2492	30	790-510
SUERC-69691 (GU42012)	TV Mammal	2450	30	760-410
SUERC-69695 (GU42013)	TIX GROB 2	2479	30	780-430
SUERC-69696 (GU42014)	TX1 Mammal	2456	30	760-410
SUERC-69697 (GU42015)	**Kaptol U-143 cattle tooth**	**2576**	**30**	**820-570**
SUERC-69698 (GU42016)	**Kaptol U-139 cattle /horse**	**2414**	**30**	**750-400**

SUERC-69705 (GU42020)	Kagovac Grob 1	2508	30	790-540
SUERC-69418 (GU42023)	Sv. Križ Horseman	2371	40	740-380
SUERC-69419 (GU42024)	Sv Petar Ludbreški 1960	2819	28	1050-900

Table 2.6. Radiocarbon dates for Kaptol, Kagocac, Sv Križ Brdovecki and Sv Petar Ludbreški (Croatia dates) (95% confidence)). The animal teeth from Kaptol have been highlighted because they were submitted to date the settlement site but were not included in the animal baseline. Calibration curve: Reimer et al. (2013). OxCal software: Bronk Ramsey and Lee (2013). (S. Harris pers. comm. 2017).

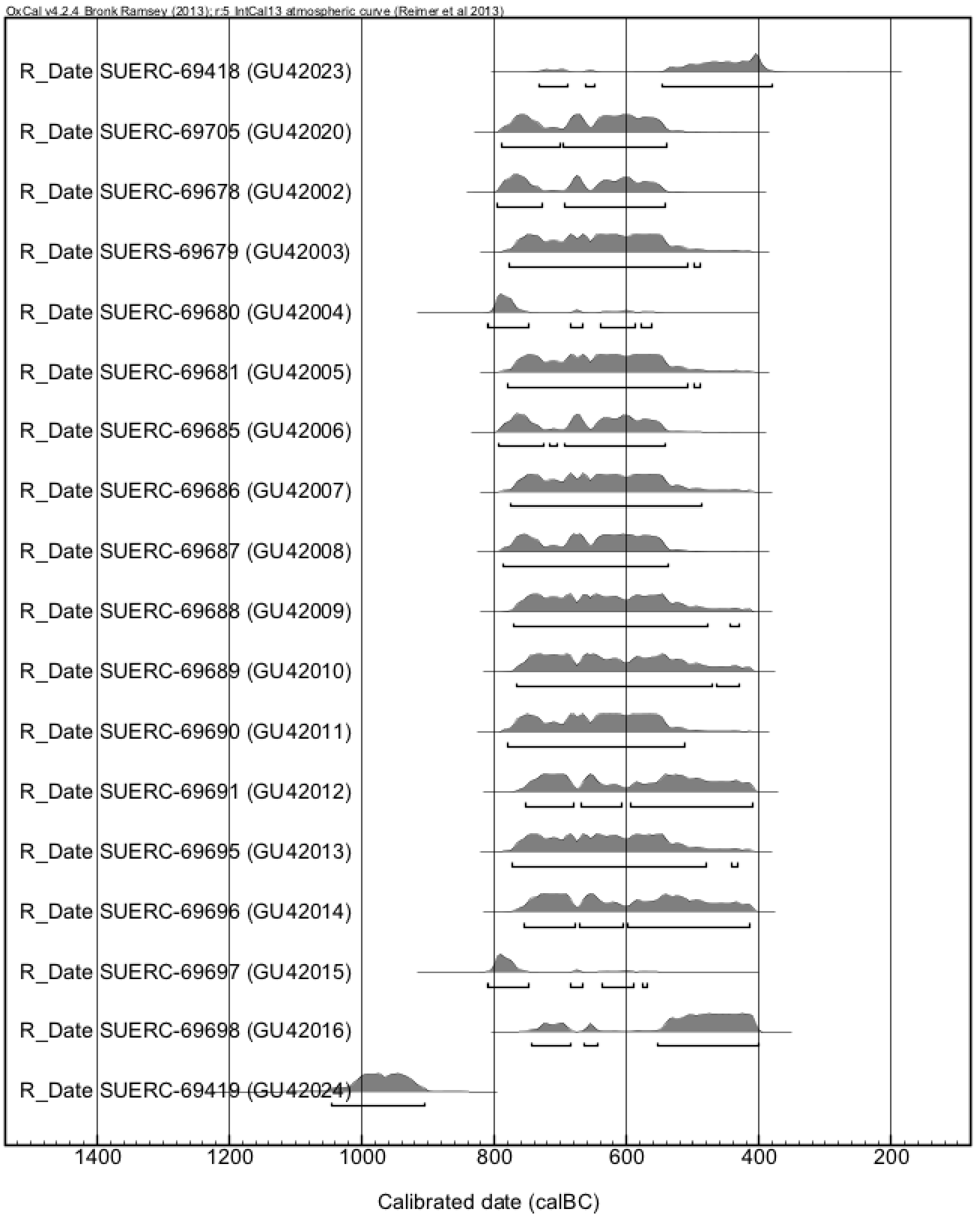


Figure 2.7. OxCal plot of radiocarbon dates from Kaptol, Kagocac, Sv Križ Brdovecki and Sv Petar Ludbreški (Croatia dates) (95% confidence)). (*Calibration curve: Reimer et al. (2013). OxCal software: Bronk Ramsey and Lee (2013). (S. Harris pers. comm. 2017).*

2.3 The carbon and nitrogen isotope animal baseline

To provide a baseline for human carbon and nitrogen isotope ratios, a number of domesticated and wild animal bones were collected. To be as comparable as possible with human skeletal remains, animal bones were sampled from contemporary settlement sites, close to the cemeteries included as part of the ENTRANS project (Table 2.7, Figure 2.8). In some instances, it was possible to source the animal bones from the graves themselves (e.g. Zagorje ob Savi). These animal bones were included in the radiocarbon strategy to ensure they were broadly contemporary with the human remains.

Settlement/site	*Species*	*Number*
Zagorje ob Savi	Cattle	3
	Pig	2
	Deer	1
Metlika	Cattle	1
	Pig	2
Gorenja vas	Cattle	3
	Pig	2
	Sheep/goat	1
Ljubljana Congress Square	Cattle	1
	Pig	2
	Sheep/goat	2
	Deer	2
CRT	Cattle	1
	Pig	2
	Sheep/goat	1
Novo mesto	Cattle	1
	Pig	1
Tribuna	Sheep/goat	1
Ljubljana SAZU	Trout	1

Table 2.7. Information regarding the source of animal bones for the carbon and nitrogen isotope animal baseline

Radiocarbon dates

The animal carbon and nitrogen isotope baseline was constructed as a means of accounting for regional or environmental variation in the isotopic composition of diet across the study area (Figure 2.8). For this to be reliable it is also important that the animal bones included were as contemporary to the human population under investigation as possible. As it was not feasible to radiocarbon date every animal that was sampled for carbon and nitrogen stable isotope analysis, at least one animal from each site was submitted. The results can be viewed in Table 2.8 and in Figure 2.9. Animal bones from Zagorje ob Savi were not radiocarbon dated as they were found in the graves of humans, which have been radiocarbon dated.

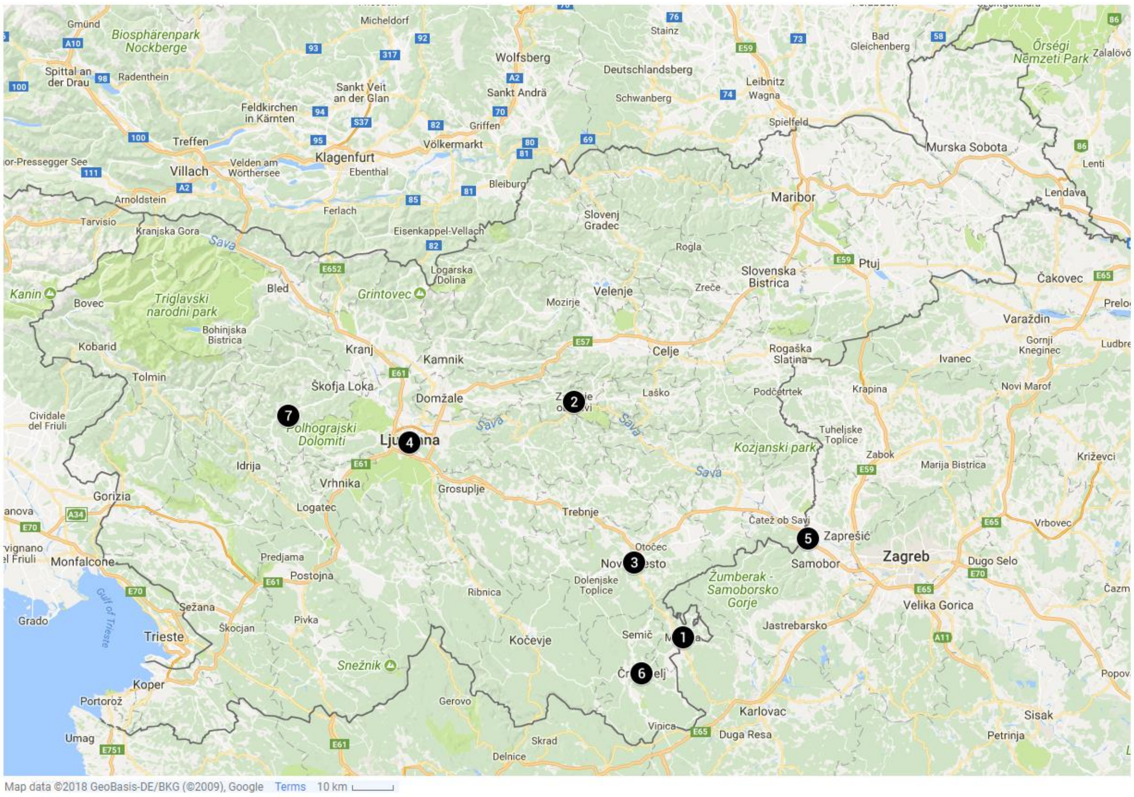


Figure 2.8. Map presenting the locations animal remains used to construct the carbon and nitrogen isotope baseline were excavated. 1) Metlika; 2) Zagorje ob Savi; 3) Novo mesto; 4) Tribuna and Congress square; 5) Obrežje; 6) Črnomelj-zupnisce and CRT; 7) Gorenja vas.

Laboratory code	Sample	BP	+/-	Calibrated Age Range (years BC) 95% confidence
SUERC-69440 (GU42040)	Obrežje cattle	1686	29	250 - 420 cal. AD
SUERC-69441 (GU42041)	Obrežje cattle	1771	29	130 - 350 cal. AD
SUERC-69726 (GU42058)	Novo mesto pig	2113	30	340 - 40
SUERC-69727 (GU42059)	Novo mesto cattle	1128	30	770 – 990 cal. AD
SUERC-69710 (GU42045)	Tribuna R05	2434	31	760-400
SUERC-69711 (GU42046)	Metlika sonda 1 kv12 se o15	2041	30	170 cal. BC – 30 cal. AD
SUERC-69715 (GU42050)	Congress square pig 1	2528	31	800 – 540
SUERC-69725 (GU42057)	Congress square 30108	2469	31	770 – 430
SUERC-69716 (GU42051)	Črnomelj-zupnisce kv 52 sonda 12	2554	30	810 – 550
SUERC-69717 (GU42052)	Gorenja vas sheep	2107	30	210 cal. BC – 40 cal. AD
SUERC-69718 (GU42053)	Gorenja vas pig	2063	31	180 cal. BC – 10 cal. AD
SUERC-69719 (GU42054)	Gorenja vas cattle	2123	30	350 cal. BC – 50 cal. AD
SUERC-69720 (GU42055)	CRT-97 Sheep	2559	31	810 - 550
SUERC-69721 (GU42056)	CRT-98 se154 kv48	2507	31	790 - 530

Table 2.8. Radiocarbon dates for animal candidates for the carbon and nitrogen isotope baseline (95% confidence). Dates that have been highlighted in red represent animals that have not been selected for the isotope animal baseline as they are not contemporary with human remains. Calibration curve: Reimer et al. (2013). OxCal software: Bronk Ramsey and Lee (2013). (S. Harris pers. comm. 2017).

For the most part, animal bones have been radiocarbon dated to the Early Iron Age, though some have been dated to the Late Iron Age. For the purposes of the ENTRANS animal baseline, this is largely acceptable, although not ideal for humans dating to the Bronze Age, such as those buried at Obrežje. In some instances, animal bones have been dated to later time periods, such as the Roman (Metlika and Obrežje) and Medieval periods (Novo mesto). These animal bones are, therefore, not comparable with the humans and have consequently been removed from the baseline.

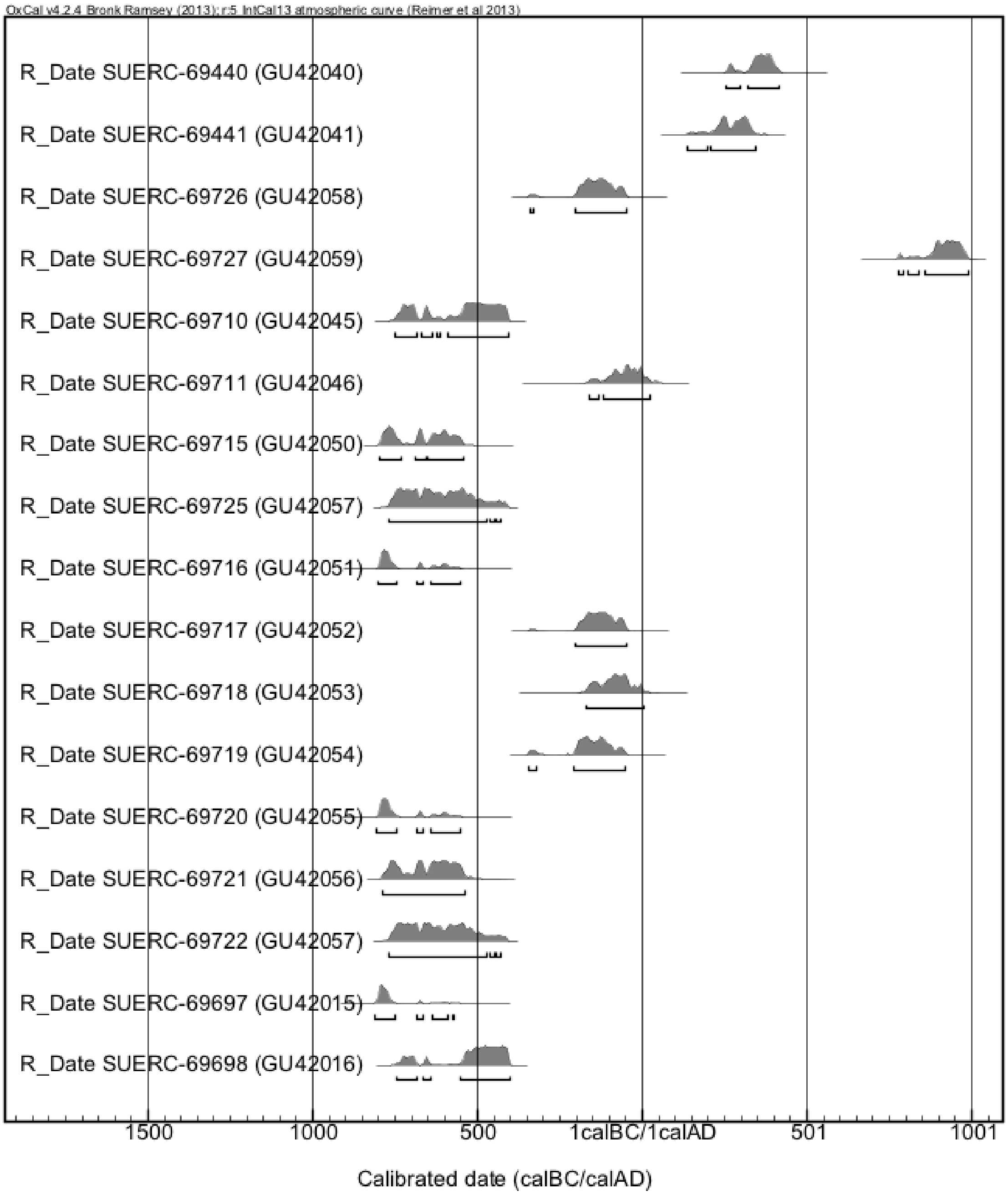


Figure 2.9. OxCal plot of animal candidates for the carbon and nitrogen isotope animal baseline, plus Kaptol settlement dates (cattle /horse teeth, See 2.3.1, Kaptol) (95% confidence)). Calibration curve: Reimer et al. (2013). OxCal software: Bronk Ramsey and Lee (2013). (S. Harris pers. comm. 2017).

Chapter 3 Methods

3.1 Osteological analysis

This section of the chapter introduces and discusses the methods selected for the osteological analysis of human remains. Unless stated, all analyses were carried out by the author at the University of Bradford.

3.1.1 Unburnt skeletal remains

The osteological analysis of unburnt human remains was vital to the successful completion of this research. To address any of the research aims, it was first essential that the osteological context of the skeletal material selected was known. To form clear and reliable interpretations from the analytical data regarding social structure, status, identity or gender, the demography (age and sex) of individual cemeteries was fundamental. As this had not been carried out previously, the osteological analysis of human remains was the initial phase of this study.

Preservation and completeness

For many of the sites under investigation, the level of preservation was a key consideration throughout this research. Poor preservation can limit the nature of information gleaned from the osteological analysis (Bytheway and Ross 2010). The burial conditions within the study area are predominantly detrimental to bone preservation, which has led to the complete destruction of many skeletons. Although individual cemetery sites were selected based on better levels of preservation, the skeletal remains examined as part of the ENTRANS Project have been similarly compromised by these adverse conditions, leading to cortical exfoliation, root etching and water damage, as well a variable (usually poor) level of completeness. Strong evidence suggests that this post-mortem fragmentation and incompleteness is unrelated to funerary treatments or human activities, for example, excarnation, because human remains are found in supine, articulated positions. The preservation of skeletal remains has had a considerable effect on the age and sex data available, as well as on the ability to recognise pathological lesions.

It should be noted that the term ‘preservation’ refers to the condition of the bone itself, for example, the level of post-mortem damage to the cortical surface, weathering, colour change or loss of the organic component (e.g. collagen). The level of bone preservation, in this case, is unrelated to the completeness of the remains (i.e. what percentage of the skeleton survives), or how fragmented the skeleton was. The preservation of each skeleton was noted on individual recording forms (Appendix A, Disk 1), including details of weathering, loss of cortical bone and texture. The completeness of each skeleton was recorded as a roughly estimated percentage, for example, most skeletons were <25% complete. As the osteological analysis of unburnt skeletal remains was carried out for age and sex data to support other analytical analyses, no specific standards for fragmentation or preservation were applied, as this fell outside the remit of this project.

The following constitutes a selection of methods utilised for the analysis of human remains, where the preservation of the individual was sufficient to allow for their application.

Minimum number of individuals

The minimum number of individuals (MNI) was used for the identification of multiple individuals and when dealing with a collection of co-mingled remains from a single grave, urn or any other context. Additionally, for the site of Križna gora, this method was applied where remains had become mixed post-excavation and unexpected elements could be identified (see Section 2.2).

Biological sex

The methods selected for the assessment of sex are dependent upon the level of preservation and completeness of the remains recovered. The stage of development also plays a vital role, as individuals who have not yet reached puberty do not exhibit the same sexually dimorphic traits as fully developed individuals (Mays 1998: 36; Scheuer and Black 2000: 343). These traits develop as an effect of the release, or absence, of hormones during adolescence which leads to differences in size and robusticity (Mays 1998: 36). An extended growing period in the pelvic region of females' results in a broadening in areas directly related to the development of the birth canal, thus becoming sexually dimorphic (Mays 1998: 33-36). It has been argued that prior to this stage of development the assessment of sex is not possible, though some have also argued that sex may still be assessed from foetal and perinatal remains and some attempts have been made to establish methods based on permanent tooth crown measurements and cranial features in older children, with varying success (Molleson et al. 1998; Scheuer and Black 2000: 343; Loth and Henneberg 2001). In the current study, non-adult remains were not included in the assessment of biological sex.

Sexually dimorphic traits are also observable in the skull and can be used in conjunction with pelvic traits to carry out an assessment of biological sex. In regards to the skull, combinations of skeletal elements and landmarks commonly used to assess sex include the mental eminence, nuchal crest, gonial angle, glabella, mastoid processes and supraorbital ridges are usually more prominent in males (Mays 1998: 33-37; Walker 2008).

Post-cranially, methods examining areas of the pelvis have proven to be the most reliable indicators of biological sex, as differences are directly related to differences in function and the development of the birth canal (Mays 1998: 33-37; Scheuer and Black 2000; Klales et al. 2012). In females, this manifests as a number of characteristics, including a wider, more U-shaped sub-pubic angle, the developments of a ventral arc, the presence of a sub-pubic concavity and a ridged medial border of the inferior pubic ramus (Phenice 1969; Mays 1998: 33-37; Klales et al. 2012). Unfortunately, the *Ossa coxae* are particularly prone to post-depositional damage (Walker 2005). For this reason, it is not always possible to utilise all the previously mentioned observations for the assessment of biological sex. Assessments based on ordinal scales, such as that of Walker's (2005) method for sex assessment using the greater sciatic notch reduce the effects of the subjective nature of sex assessment methods introduced when observing skeletal elements. This method has the added advantage of remaining effective when examining fragmentary material, as this location on the pelvis has been found to be more resistant to postmortem damage (Walker 2005).

To improve the precision of sex assessment across a sample of individuals, discriminate function analysis can be utilised. This method assigns individuals into two or more categories on the basis of a number of observed traits characteristic of those comprising the sample (Giles and Elliot 1963; Walker 2008: 311-329; Ousley and Jantz 2012; Ousley and Jantz 2013). It has been argued that discriminant function analysis provides more reliable results as, even though the accuracy values are similar to those of visual examination alone (i.e. the greater sciatic notch, cranial features etc.), the observations are less subjective (Giles and Elliot 1963; Walker 2008; Ousley and Jantz 2012: 320-321; Ousley and Jantz 2013). However, this method of sex assessment (Fordisc 3) was created based on a reference collection including ninetieth, twentieth and modern Americans that make up the Forensic Data Bank (FDA). It has already been recognised that the modern American data does not provide an appropriate reference collection for nineteenth-century Americans. This is because modern Americans have undergone significant “secular changes” in their cranial and post-cranial skeletons, which noticeably affects classifications made using the Giles and Elliot (1963) method of discriminate function analysis (Ousley and Jantz 2012: 320-321; Ousley and Jantz 2013). The use of this method using the FDA reference collection is most appropriate for modern forensic cases and, therefore, its use as a basis of sex assessment methods applied to Iron Age Slovenian populations would be fundamentally problematic (Ousley and Jantz 2012; Ousley and Jantz 2013). For this reason, discriminate function analysis was not selected for this investigation.

The following traits/methods were utilised for the analysis of biological sex: greater sciatic notch, pre-auricular sulcus (Walker 2005), ventral arc, sub-pubic concavity, ischiopubic ramus (Phenice 1969; Klales et al. 2012), nuchal crest, supra-orbital margin, glabella, mastoid process, mental eminence (Buikstra and Ubelaker 1994; Walker 2008), parietal eminences, posterior zygomatic arch, the shape of the orbits and orbital margins, gonial angle and presence or absence of gonial flaring (Brothwell 1981: 59-61; İşcan and Steyn 2013: 160-169).

Biological age

The estimation of biological age becomes less precise as the age of the individual increases. For non-adults (c. <20 years), the estimation of age is carried out through the observation of stages of skeletal and dental development (Bass 2005: 12). This has been shown to occur in a largely uniform and predictable fashion, with bones fusing at expected times and the development and eruption of teeth happening at well-documented ages, providing narrow age ranges (Scheuer and Black; Bass 2005: 12; AlQahtani 2010).

Tooth formation begins around 6 weeks in utero, with the permanent dentition (excluding the third molar) complete by approximately 15 years of age (AlQahtani 2010). The third molar, if present at all, shows more variation in formation time and eruption than the rest of the dentition, but is generally complete and fully erupted between 16 and 23 years of age (Scheuer and Black 2000: 157-160; AlQahtani 2010). As this uniform process of development is well understood, it can be used to reliably attribute a highly precise and accurate chronological age to individuals throughout childhood (AlQahtani 2010). This can be done in reference to dental atlases, such as that produced by Al'Quatani and colleagues (2010), which attribute an average age to different stages of root formation and enamel mineralisation (AlQahtani 2010; AlQahtani et al. 2014).

Dental development and eruption are arguably the most reliable age estimation method, as it would seem that they are minimally affected by factors such as malnutrition or disease (Saunders et al. 1993). If the dentition is damaged or not recovered, methods of observation related to the rest of the skeleton can be employed. Growth and bone fusion have been documented to occur at reasonably well defined developmental stages throughout childhood, adolescence and early adulthood (Saunders et al. 1993; Bello et al. 2006). However, these indicators can be more easily influenced by extrinsic factors, such as malnutrition. Factors such as stunted bone growth and premature fusion of epiphyses can lead to the underestimation of age. There is, therefore, occasionally a disparity between dental and skeletal age estimates. If this occurs, then the dental age should be given more weight, as it probably reflects a result closest to the actual biological age of the individual.

Once all the bones have fused, it becomes more difficult to estimate the biological age of an individual, as methods rely more heavily upon degenerative changes, particularly around the joint surfaces. These changes may occur at varying rates among individuals or populations and are far less uniform than that of skeletal and dental development (Franklin 2010). These changes are more likely to be influenced by extrinsic factors such as disease, activity and the environment (Mays 2015). The effects of post-depositional change and taphonomy can also be a barrier to analysis, where joint surfaces have been destroyed or diagnostic bone elements are missing.

Table 3.1 provides a list of methods used for the estimation of biological age, which were selected where completeness and preservation levels allowed for their application. Dental wear (Brothwell 1981) was used with caution due to a lack of published, calibrated, population-specific standards. Due to the low number of well-preserved juvenile jaws, it was not possible to calibrate dental wear for the study area.

Supporting evidence was taken from late fusing epiphyses, such as the sacral bodies (Belcastro et al. 2008), iliac crest and the medial clavicle (Webb and Suchey 1985), which can be used as a further method for the age estimation of younger adults. These methods are useful for the narrowing of age ranges of young adult individuals, which could include individuals in their late teens, who have ceased in growth in height (i.e. complete fusion of long bone epiphyses) (Scheuer and Black 2000: 468).

Due to the generally poor correlation found between the estimated biological and actual age of known age-at-death adult skeletons in other studies, coupled with consideration of the very poor preservation of the skeletal material included in this study, broad ranges of young, middle and mature adult were considered more appropriate than numerical age ranges (Table 3.2) (Buikstra and Ubelaker 1994). These ordinal categories better reflect biological rather than chronological age and facilitate the comparison of populations. For individuals who were observed as being an adult, but where the more precise estimation of biological age was not possible, a category of adult (c. 20+ years) was used. Age ranges for non-adults are also quoted in Table 3.2. Actual age ranges (numerical) obtained during the estimation of age were recorded during the analysis and can be found in Appendix A, Disk 1.

Non-adults	
Dental atlas of development and eruption.	AlQahtani 2010
Fusion of epiphyses	Scheuer and Black 2000
Long bone length (foetal remains)	Scheuer et al 1980
Adults	
Age-related change of the pubic symphysis	Brooks and Suchey 1990
Age-related change of the auricular surface	Buckberry and Chamberlain 2002
Cranial suture closure	Meindl and Lovejoy 1985
Dental wear	Brothwell 1981

Table 3.1. Osteological methods used for age estimation

Term	Age range
Non-adult (adapted from Scheuer and Black 2000: 468)	
Infant	from birth to the age of 1 year
Early childhood	c.1 – 6yrs
Late childhood	c.7 – 12 years
Adolescence	13-19
Adult (Buikstra and Ubelaker 1994)	
Young adult	c.20-35 years
Middle adult	c.36-50 years
Mature adult	c.50+ years

Table 3.2. Explanation of age ranges

In order to produce the most precise age estimate for an adult individual a combination of observable traits can be taken, followed by the employment of Transition Analysis (Boldsen et al. 2002). This method considers the linear patterns of change in several specific areas of the skeleton linked to increasing age. These are recorded as a series of scores, which are then entered into a computer program that calculates the maximum likelihood and confidence intervals for age at death (Boldsen et al. 2002). This method relies heavily on the presence of specific cranial (suture closure) and pelvic (pubic symphysis and auricular surface) traits (Boldsen et al. 2002). Unfortunately, because of high levels of incompleteness and taphonomic damage, only 2% of skeletons had a pubic symphysis and 8% an auricular surface. Crania were very poorly preserved and very fragmented and so cranial suture closure was also not a viable trait. It was decided a methodology that could be applied to the whole skeletal assemblage was preferable to the use of a method that could only be used in very rare cases. For this reason, Transitional analysis was not selected for this investigation.

3.1.2 Cremated bone

Following a preliminary assessment of cremated human bone from a number of cemetery sites, three key assemblages were selected for further analysis. These were the urnfield cemeteries at Ljubljana SAZU and Kapiteljska njiva, and the two Early Iron Age necropolises at Kaptol. These assemblages had the best potential to address research questions regarding cremation processes and pyre technology, but also appropriate approaches to the dead based on cultural beliefs. This addresses the major aims of this research by:

- Assessing the demography (age/sex) of each cemetery to consider homogeneity/heterogeneity within and between groups.
- Exploring how the treatment of the dead by the living was related to the personhood and identity of the deceased.
- Considering how the treatment of the dead by the living reflected local cosmology and beliefs of life, death and transformation.
- Investigating how the analysis of cremated remains can inform our understanding of evolving mortuary practices, such as Iron Age inhumation burial.
- Combining this information with data from other disciplines (e.g. isotope analysis) to consider multiple facets of lifestyle during the Late Bronze Age/Early Iron Age.

Cremated bone should be recorded in a different manner to that of unburned bone because of the different taphonomic pathways and properties (Buikstra and Ubelaker 1994: 5-10; McKinley 2004: 4). It has been suggested that cremated human remains may stand a better chance of surviving in the archaeological record than inhumation burials, especially in either highly acidic or alkali soils, due to the widespread practice of collecting burnt remains and placing them in vessels before burial (McKinley 1994a). Consequently, the bones undergo less exposure to the burial environment and are, therefore, less prone to diagenesis and destruction (McKinley 1994a). If the remains were interred directly into the ground the burned bone could still survive better than unburned bone, as it has a higher mechanical strength and is less prone to microbial attack due to the lack of organic fractions (Shipman et al. 1984; Mays 1998: 209;223). However, remains are commonly observed to be far more fragmented than that of unburnt bone and this was also the case in the current study.

The osteological analysis of cremated remains has been carried out following methods adapted from those utilised for the analysis of inhumed individuals. Standard methods were used as published in the BABAO guidelines (McKinley 2004: 9-13), using sieve fractions of 2mm, 5mm and 10mm. The methods acknowledge the greater fragmentation, poor preservation and completeness of the assemblages; variables that can significantly affect the data recovered from the analysis of cremated human remains (McKinley 2004: 9-13). Incomplete recovery of an individual, both from the pyre and during the excavation of a grave, can pose problems when assessing the minimum number of individuals present, as well as age estimations and sex assessments.

The process of cremation results in a range of surface and colour changes, as well as shrinkage, fracturing and warping. The identification of curvilinear/curve-transverse fractures indicates the presence of soft tissue and surviving organic matter within the bone (e.g. collagen) at the point of cremation, as these fractures occur as this tissue is burned away (Symes et al. 2015: 42-46). The burning of de-fleshed, dry bone results in different patterns of fracturing, commonly longitudinally with more regular edges (Gonçalves et al. 2011). The burning of dry bone also results in less shrinkage and warping as some of the organic fraction has already been leached away (Ubelaker 2009; Gonçalves et al. 2011).

Sex

Due to the changes in bone shape and high level of fragmentation linked with cremation, the methods described in Section 3.1.1 become problematic. Diagnostic areas such as the nuchal crest, the supraorbital ridge and mastoid processes of the skull can assist with assessments, but the use of the arguably more reliable methods utilising the pelvis is rarely possible (McKinley 2000: 408; Wahl 2008: 148). Metric analysis of the teeth is similarly not applicable to cremated remains as the tooth crowns commonly shatter due to the differing thermal properties of the dentine and enamel (Wahl 2008: 147).

General observation of the robusticity of the bones could lead to assessments of male or female, though metric analysis is not recommended for the analysis of cremated remains due to the high prevalence of shrinkage, fracturing and warping (McKinley 2008b: 409-412). This means of sex assessment is limited and would likely lead to the misidentification of individuals, as there is a probable chance of overlap between the two groups, based on size alone (McKinley 2000: 409-412). Additionally, as work of this nature has not been previously published from Slovenia or northern Croatia, there has been no calibration or identification of a population norm.

Age

Depending on the level of burning, a number of the methods commonly used for the ageing of inhumed skeletons can be assigned to cremated remains (McKinley 2000: 408; Wahl 2008: 147). However, with increased exposure to intense heat, enamel crowns can be shattered, metaphases disintegrate and sutures which have not yet fully fused can be forced apart (Wahl 2008: 147). This can lead to the age estimation of cremated individuals becoming very difficult. It has been argued that the overall size and robusticity of the bones can allow for the broad categories of child versus adult (McKinley 2004; Wahl 2008: 147). More precise brackets are usually not possible unless un-erupted teeth or diagnostic areas, such as the auricular surface, have survived the cremation process (Wahl 2008: 147). The identification of fused or unfused epiphyses and annular rings also assisted the age estimation of cremated individuals (McKinley 2004).

Cremated remains: other analyses

The cremated individuals have additional potential for further analyses, including the recording of weight, colour and level of fragmentation. This can indicate the level of modification to the recovered bone, which in turn could indicate the effectiveness of the cremation process (McKinley 1993; McKinley 2008b). The preservation and completeness of cremated remains are highly variable and are dependent on a wide range of factors. The length of time and temperature at which a corpse is cremated is strongly correlated to the level of oxidation in the bone (Shipman et al. 1984). The level of the bones structural change (e.g. organic and carbonate content, and crystallinity) is related to time, temperature and the fuel used, but also weather conditions (high winds or rain can have cooling effects) and whether or not the corpse was still fleshed at the time of burning (McKinley 2000: 407; McKinley 2008b: 168; Symes et al. 2015: 30-34). Fleshed bodies provide protection to bony elements, particularly in the pelvis and the phalanges (Symes et al. 2015: 30-34). The latter elements have been found to be shielded by the “pugilistic pose”, or the contraction of flexor muscles in the hand, leading to the curling of the fingers and therefore a clenched fist (Symes et al. 2015: 30-34).

Bone colour

Although a specific relationship between bone colour and intensity of burning and/or duration of heat exposure has been proven insecure and variable, a general sequence of colour change has been established. This sequence has been approached as a continuum of colour change, where a single bone can exhibit several different colours. Table 3.4 provides some of the findings of heating experiments and other publications, where bone colour has been associated with ranges of temperatures (when burned in air). These ranges vary from study to study but do largely overlap, with black attributed to around 300-400°C, blues and greys c. 400-650°C, and white dominating after 650°C.

The colour of the bone indicates the temperature of the bone, rather than the fire itself (Mays 2010). For a bone to be fully calcined/white throughout, the bone would have to have reached at least 650°C and, moreover, for the duration of heat exposure to have been sufficient for heat to penetrate the full thickness of the bone (Figures 3.2 to 3.6) (Walker et al. 2008; Mays 2010; Devlin and Herrmann 2015).

The bone colour change is caused as the structural components of the bone become increasingly altered. Stages of thermally induced modification have been presented in Table 3.3. Darker colours of black or purple indicate survival of the organic component (likely chemically altered) of the bone and, therefore, either a shorter time exposed to heat or a lower temperature (300-400°C) (Walker et al. 2008; Devlin and Herrmann 2015). Lighter colours of white and light grey indicate where the organic component of the bone has been completely removed and the crystalline structure of the inorganic matrix has also changed (Walker et al. 2008; Devlin and Herrmann 2015).

Stage 1	**Dehydration:** the breaking of hydroxyl bonds resulting in the loss of water	~600°C
Stage 2	**Decomposition:** the destruction and removal of organic components	500-800°C
Stage 3	**Inversion:** the loss of carbonates	700-1100°C
Stage 4	**Fusion:** the melting of crystals	>1600°C

Table 3.3. Stages of thermally induced modification to bone (Devlin and Herrmann 2015)

To further investigate colour change and to infer patterns of differential burning across the body, colours were recorded separately from the cranial, axial, upper limb and lower limb. By doing this, the progression and completeness of the cremation process can be inferred. For example, if the limb bones were observed as white or grey, this would suggest that the bone reached higher temperatures of over 650°C, which would probably indicate that the flesh and soft tissues surrounding these bones had been destroyed (Devlin and Herrmann 2015). Conversely, if, for example, the bones of the axial skeleton (ribs, vertebrae and pelvis) were of a darker colour (black, brown or purple), it could be argued that the bone only reached temperatures of 200-400°C (Walker et al. 2008; Mays 2010; Devlin and Herrmann 2015). From this, it could be inferred that soft tissues were not completely removed and, therefore, the cremation process was incomplete (Devlin and Herrmann 2015). By dividing the skeleton into different regions, different patterns of burning can be inferred.

Publication	Colour description	Associated temperature
Bonucci and Graziani 1975 (cited in Devlin and Herrmann (2015))	Brownish colours	200-300°C
	Black	300-350°C
	Greys	550-600°C
	White	>650°C
Shipman et al 1984	Pale yellow and very pale brown	<285°C
	Pink and black with secondary colours of very dark greyish-brown and brown, reddish-brown, and very dark grey	285-525°C
	Natural black, medium blue and some reddish yellow and light grey. Secondary colours of brown and brownish-grey	Up to 645°C
	Natural white and light blue/grey	940°C
McCutcheon 1992	Pale brown to black	340°C
	Light brownish grey	600°C
	White dominating	>650°C
Walker 2008	Dark brown to black	200-300°C
	Fully calcined/white	800°C
Mays 2010	Orange, reddish, dark brown	~200°C
	Black	300-400°C
	Progression through tan to grey	400-650°C
	Predominately white	650-800°C

Table 3.4. Publications on the relationship between temperature and bone colour and their findings

Figure 3.1. Sacrum fragment from Ljubljana SAZU displaying examples of grey and blue

Figure 3.2. Cranial fragment from Ljubljana SAZU displaying examples of black and brown

Figure 3.3. Cranial fragment from Ljubljana SAZU displaying examples of white, black and purple

Figure 3.4 Fully calcined and white long bone fragments from Kapiteljska njiva, grave 140

Figure 3.5 Examples of long bones from Ljubljana SAZU where the surface cortical bone is white, but where the heat has not penetrated the thickness of the bone, leaving blue and black within

Deposit weight and bone fragmentation

In addition to its structural modification, the weight and fragmentation of the cremated remains are suggestive of the proportion of the body represented in the final grave deposit. The total cremated remains of an adult can weigh between 2000–3000g, but this has been known to vary in archaeological samples (McKinley 2013). For example, McKinley (2013) suggests that only 40-60% of the expected bone weight for an adult is generally found in the UK from Late Iron Age cremations, and that Iron Age graves in the British Isles tend to have lower weights than those dating to the Bronze Age.

From the analysis of cremated human deposits, ideas regarding how the body was viewed post-cremation can be inferred. For instance, was it important for the whole person to be buried? Or were a few chosen elements from the pyre sufficient to represent the deceased? Patterns in the frequency of elements identified, such as cranial, axial skeleton (ribs, vertebra etc.) or long bones can be examined regarding these questions (Williams 2004; Williams 2015). For this reason, weights were recorded for the categories: skull; upper limb; axial skeleton and lower limb.

In later chapters, Osteological data will be combined with evidence from isotopic data to yield more detailed interpretations regarding the identity of those living in the south-east Alps and the Pannonian plain during the Late Bronze Age and Early Iron Age.

3.2 Stable isotope analysis: an introduction to basic concepts

An ‘isotope’ is one form of an element – characterised by the number of protons found in the nucleus – which differs from other forms of the same element because of a different number of neutrons. This results in all the isotopes of a single element having a different atomic mass. Each element may have several isotopes, which occur in nature in different abundances (Pollard et al. 2007: 230-233). For the analysis of stable isotopes in archaeological science, differences in the isotopic composition of materials, such as bone collagen, are reported as delta values (δ), which are defined by the following formula, where R represents the isotope ratio (e.g. $^{15}N/^{14}N$):

$$\delta = \frac{R_{sample} - R_{standard}}{R_{standard}} \times 1000$$

Multiplication by 1000 converts values to units of parts per mil (‰), relative to the appropriate international standard (Yun and Ro 2008). Delta values obtained from the tissues of organisms are subject to, and therefore indicative of, influences such as temperature, altitude, diet and metabolic processes (Sponheimer and Lee-Thorp 1999; Harrison and Katzenberg 2003; Hedges and

Reynard 2007). Any variation observed in these isotope ratios are determined by isotopic fractionation in the environment or within the body. One focus of the current investigation is diet and metabolism.

3.2.1 Carbon and nitrogen: stable isotope analysis of collagen for dietary reconstruction

Human bones and tooth dentine are made up of two fractions: approximately 70% (dry weight) is a hard, mineral bioapatite and the remainder is a flexible organic component, which is predominantly type I collagen. Collagen is a structural protein made up of long peptide chains. When extracting collagen from bone and dentine for light isotope analysis, it is the protein aspect of the diet that is under investigation, rather than the isotopic composition of the whole diet (Tykot 2004). The variation in mass between isotopes of the same element leads to a process known as isotopic fractionation. This will occur, for example, during the breakdown and absorption of elements from the diet into bodily tissues. It is caused by the 'kinetic isotopic effect', whereby lighter isotopes are preferentially utilised and heavier isotopes are discriminated against. This commonly leads to the enrichment of the lighter isotopes in reaction products. When considering stable light isotope data, it is predominantly the effects of this fractionation that are being observed, and these can subsequently be used to investigate themes of diet and health. Comprehensive reviews regarding the stable isotope analysis of bone and dentine collagen include Tykot 2004; Hedges and Reynard 2007; Reynard and Tuross 2015. The following provides an introductory overview of carbon and nitrogen stable isotope analysis.

<u>Carbon</u>

Carbon delta values ($\delta^{13}C$) are calculated as the relative abundance of stable isotopes ^{13}C and ^{12}C, relative to the international standard: Vienna PeeDee Belemnite (VPDB). Archaeological skeletal material has less ^{13}C relative to VPDB and is therefore always recorded as a negative value. $\delta^{13}C$ values of collagen extracted from bone and tooth dentine have most frequently been used in the investigation of paleodiet (Harrison and Katzenberg 2003; Pearson et al. 2015). This is possible due to isotopic fractionation occurring during photosynthesis and diffusion, creating distinct ranges of values which can be related to constituents of diet (Tykot 2004).

C3/C4 photosynthetic pathways

Most plants – temperate grasses (wheat, barley etc.), fruits and vegetables – follow the C3 photosynthesising pathway. In more arid locations, plants such as maize and millet have adapted to follow the C4 photosynthesising pathway. The latter pathway results in higher (less negative) $\delta^{13}C$ values (Tykot 2004; Tieszen 1991; Tafuri et al. 2009). This difference between pathways results in distinct ranges of values indicative of the consumption of either vegetation type (Tieszen 1991; Tafuri et al. 2009). If an individual was consuming a mix of C3 and C4 plants, this would be exhibited in the isotopic data as a $\delta^{13}C$ value in-between these two extremes (O'Leary 1981; Merwe 1982; Farquhar et al. 1989; Lee-Thorp et al. 1989).

Marine/terrestrial

$\delta^{13}C$ values are similarly used as a means of differentiating between the terrestrial and marine food chains. Higher $\delta^{13}C$ values are produced by individuals who maintain a predominantly marine protein-based diet (Richards and Hedges 1999; Richards 2003). This differentiation between marine and land-based carbon sources is the result of the photosynthesis of dissolved CO_2 by phytoplankton in the oceans, which involves a lower degree of fractionation than photosynthesis by terrestrial, C3 plants (Chisholm et al. 1982; Richards and Hedges 1999; Richards 2003). Due to the distinction between marine and land-based carbon sources, the bone collagen of an individual from Europe consuming a wholly marine protein diet would exhibit $\delta^{13}C$ values of around -12 ± 1‰, while someone whose animal protein source was entirely land-based would show values of around -20 ± 1‰ (Richards and Hedges 1999; Richards 2003). Individuals consuming a mixture of both marine and terrestrial protein would be expected to fall somewhere in-between these ranges, depending upon the relative proportions of each component source (Richards and Hedges 1999).

Enamel carbonate

Carbon isotope ratios can also be measured from the apatite fraction of human/animal tooth enamel and bone ($\delta^{13}C_{carb}$). This carbonate fraction of hard tissues is formed from bicarbonates dissolved in the blood (Lee-Thorp et al. 1989; Loftus and Sealy 2012). This differs from the $\delta^{13}C$ ratio obtained from bone and dentine collagen because it is influenced by carbon from the whole diet, including carbohydrates and lipids, whereas $\delta^{13}C$ from collagen is largely routed from dietary proteins (Lee-Thorp et al. 1989; Ambrose 1991; Ambrose and Norr 1993; Jim et al. 2004; Jim et al. 2006).

Studies have shown that the spacing between apatite and collagen ($\Delta^{13}C_{apatite-collagen}$) can assist in the investigation of dietary components, such as relative quantities of C3, C4 and marine-based foods (Lee-Thorp et al. 1989; Kellner and Schoeninger 2007; Froehle et al. 2010; Loftus and Sealy 2012). For example, Ambrose et al. (1997) argued that a $\Delta^{13}C_{apatite-collagen}$ of less than 4.4‰ is suggestive of a diet with a protein source enriched in ^{13}C compared to the whole diet. This was interpreted as a diet focussed on marine protein and C3 based plants (Ambrose et al. 1997; Finucane et al. 2006; Loftus and Sealy 2012).

Enamel carbonate isotope ratios have also been used in the investigation of childhood diet. For this, intra-individual shifts in $\delta^{13}C_{carb}$ values between teeth developing at different ages (e.g. M1 and M3) have been observed and interpreted as a change in whole diet, from a high quantity of lipids (breastmilk), to a high quantity of carbohydrates (solid foods) (Wright and Schwarcz 1998; Wright and Schwarcz 1999).

<u>Nitrogen</u>

The delta value for nitrogen ($\delta^{15}N$) refers to the relative abundance of the isotopes ^{15}N and ^{14}N in relation to the international standard: Ambient Inhalable Air (AIR). Plants and animals are usually more enriched in ^{15}N relative to AIR and so ratios are reported as positive values. Nitrogen isotopes are commonly used in combination with carbon isotopes to investigate paleodiet.

Trophic levels

Nitrogen isotope ratios produced from plants and the bone and dentine collagen of humans and animals reflect their relative trophic level or position in the food chain (Ambrose 1991; Hedges and Reynard 2007). For example, the highest $\delta^{15}N$ values are exhibited by organisms belonging to the highest trophic level, i.e. carnivores. This increase in $\delta^{15}N$ values occurs in a predictable manner known as a 'trophic level shift' and is an increase in $\delta^{15}N$ values of between 2 and 5‰ (Schoeninger et al. 1983; Schoeninger and DeNiro 1984; Hedges and Reynard 2007). This increase in values is caused by fractionation, whereby the lighter isotope (^{14}N) is preferentially lost through urea as a by-product of protein metabolism, resulting in increasingly ^{15}N enriched tissues further up the food chain (Schoeller 1999; Vanderklift and Ponsard 2003; Hedges and Reynard 2007).

Although trophic shifts have been observed to be reasonably uniform (Schoeninger and DeNiro 1984; O'Connell and Hedges 1999; Hedges and Reynard 2007), the $\delta^{15}N$ values themselves may still vary regionally based on local environments and ecosystems (Ambrose 1991). Factors such as aridity, salinity and water availability can all play a role in the variation of $\delta^{15}N$ values (Heaton et al. 1986; Ambrose 1991). Furthermore, complexities regarding the interpretation of nitrogen isotope values arise from past human activity. A key element of this is the cultivation and manuring of land for domesticated plants – particularly staples, such as cereals, which rely on obtaining nitrogen from the soil. The manuring of land has been shown to increase $\delta^{15}N$ values by varying degrees (Bogaard et al. 2007; Fraser et al. 2011; Bogaard et al. 2013). Fraser and colleagues (2011) noted that modern cereal grains from soil manured with cattle slurry had $\delta^{15}N$ values of up to 9‰ higher than grains grown in soil at the same location, which had not been manured. Different intensities of manuring led to a range of isotopic values, but overall there was a statistically significant difference between cereal grains that came from a manured soil in comparison to those which came from untreated soils. They also observed that pulses, such as beans and peas, were less likely to exhibit a manuring effect, as these species are 'nitrogen fixers', and can incorporate atmospheric nitrogen into their tissues (Fraser et al. 2011). The alteration in $\delta^{15}N$ values observed in plants grown in manured soil will inevitably result in variation in $\delta^{15}N$ values further up the food chain, which could lead to the misinterpretation of human $\delta^{15}N$ values. Multiple communities may be consuming a largely similar diet; however, depending on their methods of cereal cultivation, their $\delta^{15}N$ values could differ (Fraser et al. 2011). To reduce this complexity, it is recommended that a population-specific baseline of carbon and nitrogen isotope values is created through the analysis of local and contemporary faunal and floral remains (Fraser et al. 2011). In this way, the isotopic composition of localised food chains can be assessed, and isotope values from different populations can be compared with a higher degree of certainty (Fraser et al. 2011).

The construction of a faunal baseline has been undertaken as part of the ENTRANS Project to address this problem. An assortment of domesticated animals remains from contemporary contexts (associated settlement sites and from the graves themselves) were sampled from across the study area. The key species selected were sheep, cattle, and pig as these were most likely vital elements of the local food chain. In addition to this, a few wild animals, including deer and riverine fish, were also included. To ensure these remains were contemporary, 17 bone samples have been radiocarbon dated. Non-contemporary samples would be problematic, as differences in climate, environmental conditions or agricultural/husbandry practices could alter isotopic ratios and, therefore, make them less reliable as proxies.

Non-dietary influences

The nitrogen isotope ratios of dentine and bone collagen have also been observed to reflect non-dietary influences (Fuller et al. 2004; Fuller et al. 2005; Waters-Rist and Katzenberg 2010; Beaumont et al. 2015; Reynard and Tuross 2015). An individual's nitrogen balance is related to the amount of nitrogen excreted in relation to the amount of dietary nitrogen ingested. The body falls into a negative nitrogen balance when more nitrogen is excreted than is ingested, for example during periods of nutritional stress or disease (Fuller et al. 2005; Mekota et al. 2009; Beaumont et al. 2013b; Beaumont et al. 2015). This is also known as catabolism or a catabolic state. When this occurs, the body preferentially breaks down tissues containing the lighter isotope (^{14}N), resulting in an enrichment in ^{15}N in body tissues. This leads to a higher $\delta^{15}N$ value.

The body enters a positive nitrogen balance when less nitrogen is excreted than ingested, commonly during times of rapid growth, such as infancy and puberty (Waters-Rist and Katzenberg 2010). This is also known as anabolism or an anabolic state. During this time, more of the lighter isotope (^{14}N) is retained in the body tissues, which can result in a lowering of $\delta^{15}N$ values (Fuller et al.

2004). In the bones of adults, which have slow rates of turn-over, it is unlikely that short-lived shifts in nitrogen balance would be visible (Hedges et al. 2007; Waters-Rist and Katzenberg 2010). However, collagen from the actively forming bones and dentine of infants and children may produce values which have been influenced by variables not directly linked to diet, such as growth or metabolic disease (Beaumont et al. 2013b; Beaumont et al. 2015). For this reason, non-adult individuals were selected for incremental dentine analysis. This high-resolution sampling method has the potential to detect fluctuations in nitrogen balance. These samples could reveal any metabolic or dietary change in the actively forming tissues of individuals not surviving into adulthood. Furthermore, final dentine increments (from the apex) may represent the nitrogen balance of children around the time of death.

3.2.2 Carbon and nitrogen stable isotope analysis

Bulk collagen analysis

The numbers of collagen samples measured from different skeletal elements are presented in Table 3.5. Where possible, multiple bone elements (dentine, rib and long bone) were sampled to investigate potential carbon and nitrogen isotopic variation during the life course of an individual.

Bulk collagen			
Site	*Apex dentine*	*Rib*	*Long bone*
Križna gora	24	10	36
Dolge njive	7	7	6
Obrežje	5	3	4
Ljubljana Congress Square	1	3	2
Zagorje ob savi	2	4	3
Metlika	2	0	1
Kapiteljska njiva	0	0	0
Grofove njive	3	0	2
Sv Petar Ludbreški	1	2	0
Sv Križ	2	3	6
TOTAL	**47**	**32**	**60**

Table 3.5. Number of collagen samples measured for carbon and nitrogen Stable Isotope Analysis.

Information regarding the number and preparation of enamel carbonate samples has been given in Section 3.2.3, as enamel carbonate and oxygen isotope ratios are measured simultaneously from the same sample. Consequently, the sample preparation procedure is identical.

This method has been chosen to address all three aims of this study. Regional scale data, including collagen samples and enamel carbonate samples from all available individuals, is used to create a corpus of data. This corpus is then assessed for any inter or intra-cemetery homogeneity/heterogeneity, which could indicate variable dietary practices within or between communities. Following this analysis, the data is used to interpret themes of communal identity, gender, social structure and status.

Incremental dentine analysis

The number of teeth selected for incremental dentine carbon and nitrogen Isotope analysis is presented in Table 3.6. These teeth were sampled from non-adult individuals to investigate variation in childhood diet and metabolism in individuals that did not survive childhood. The results of these non-adult individuals were not used primarily as a method of investigating population-wide dietary trends, as this is a biased data set. These children did not survive childhood and so issues, such as the Osteological Paradox, are vital considerations when assessing any results (Wood et al. 1992). There is no way to be certain that the diet or metabolic status of these non-adults did not it some way affect or influence their deaths.

These samples were taken to address aims 1, 2 and 3. The high-resolution nature of this method is more likely to highlight heterogeneity within the carbon and nitrogen isotope ratios of a single individual. For this reason, it is particularly useful for the creation of individual biographies, such as the one presented in Chapter 7. The exploration of multiple scales of resolution using this method, in conjunction with other areas of analysis (e.g. osteological) has illustrated subtle differences in the data, resulting in more nuanced interpretations.

Individual	Age at death	Tooth
Križna gora 75	9.5 years	**Deciduous first molar** (30 weeks +/-0.5 months – 2.5 years +/-0.5 years); **permanent first molar** (4.5 months+/- 1.5 months – 10.5 years +/- 0.5 years, or death)
Križna gora 59	9.5 – 10.5 years	**Permanent second pre-molar** (2.5 years +/- 0.5 years – 14.5 years +/- 0.5 years, or death)
Ljubljana Congress Square 1029 A	10.5 years	**Permanent first molar** (4.5 months+/- 1.5 months – 10.5 years +/- 0.5 years, or death)
Obrežje 12664	6.5 years	**Deciduous first molar** (30 weeks +/-0.5 months – 2.5 years +/-0.5 years); **permanent first molar** (4.5 months+/- 1.5 months – 10.5 years +/- 0.5 years, or death)
Sv Križ 4	8.5 years	**Deciduous first molar**; (30 weeks +/-0.5 months – 2.5 years +/-0.5 years) **permanent first molar** (4.5 months+/- 1.5 months – 10.5 years +/- 0.5 years, or death)
Sv Križ Horseman	Middle adult	**Permanent first molar** (4.5 months+/- 1.5 months – 10.5 years +/- 0.5 years, or death)
Zagorje ob Savi Infant 1	c.7 months	**Deciduous first incisor** (30 weeks +/- 0.5 months – 2.5 years +/- 0.5 years)

Table 3.6. Number of teeth selected for incremental dentine analysis

Time periods reflected by collagen samples from different skeletal elements

Apex dentine

"Apex dentine" refers to bulk collagen samples taken from the apex of the tooth root. This description has been used to distinguish these bulk collagen samples from incremental dentine samples, or from mean isotope ratios that have been generated from combined incremental dentine samples from a single tooth, from crown to apex. Where these mean isotope ratios have been calculated, they have been identified as "whole tooth means". This distinction has been made as the dentine samples reflect the average isotopic composition of protein ingested during childhood. As dentine does not turnover or regenerate, whole tooth means are influenced by longer developmental time periods than apex dentine samples, probably including periods of dietary change, such as breastfeeding and weaning, which could have affected isotope ratios (Millard 2000; Fuller et al. 2006). As such, isotope ratios from apex dentine samples, which are reflective of a shorter time span, are not directly comparable with Whole Tooth Means.

Rib and long bone

The rib collagen is constantly remodelling (up to 7.7% a year for adults), and so will reflect a relatively short period of dietary consumption, prior to death (Parfitt 2002). The femur reflects a much longer average of up to 80 years of protein consumption (past the age of 20) (Hedges et al. 2007). This latter skeletal element, therefore, probably provides a lifelong average of dietary protein consumption.

All the individuals sampled for stable isotope analysis are from inhumation burials, originally thought to date to the Early Iron Age. As discussed in Section 2.2, the chronology of these individuals has been revealed as more complex following the application of radiocarbon dating. The data set includes both males and females and represents all age categories (infant, sub-adult, young adult, middle adult and mature adult).

Typologically and biologically male and female

During the interpretation of isotopic data, particularly regarding data from the cemetery at Križna gora, data was split into sex-based categories. Due to the high number of unsexed individuals (discussed in more detail in Section 4.2), sex categories included individuals assessed based on grave good typologies to assist with the investigation of possible relationships between diet and gender. Where this has been attempted, categories of Male and Female include typologically female individuals (buried with objects including spindle whorls, amber and glass beads, and ring jewellery), as well as biologically female (sex assessed using osteological methods). All the individuals included in Male categories were assessed for sex using Osteological methods.

Preparation and measurement

A combination of bulk bone collagen samples was taken from 32 ribs, 60 long bones (primarily midshaft femur but in one case a tibia was sampled, two humeri, one radius and one ulna) and 47 apex dentine samples. This sampling strategy was chosen to investigate the average isotopic composition of diet at different developmental stages

All collagen extractions were carried out following the modified Longin method (Longin 1971; Brown et al. 1988). Bone fragments (c. 300mg) were demineralised in 0.5M HCl at 4°C, which took between two and four weeks.

Bulk dentine samples were removed from the apex (c. final 2mm) of tooth roots and demineralised under the same conditions as bone. These samples reflect the isotopic composition of diet and metabolic condition of an individual in the final stages of the tooth's development (late childhood/ early adolescence or young adulthood if sampling the third molar).

For incremental dentine analysis, 1mm samples were taken from the crown to the apex of the tooth, following Beaumont et al (2013). An approximate age was attributed to each dentine section by dividing the length of time required for the enamel crown to form (using the dental atlas by AlQahtani et al. (2010)) by the number of increments sampled. The approximate ages attributed to increments represents a midpoint of tooth development of +/- 0.5 years and do not account for the lag between changing diet and the incorporation of isotope signals into forming tissues (Beaumont et al. 2013). Consequently, relationships between age and isotope ratios have not been explored in great depth. Instead, results are discussed in terms of general trends.

Once the production of CO_2 had ceased and the reaction was complete, bone and dentine samples were rinsed three times with deionised water and placed in an HCl solution of pH3 at 70°C for either 48 (bone) or 24 (dentine) hours to gelatinise. The solutions from bone collagen were filtered using Ezee filters, followed by centrifugal filtering using Millipore ultrafilters. The final liquid from dentine and bone samples was freeze-dried, weighed in duplicate and measured at the University of Bradford Isotope Facility by combustion in a Thermo Flash EA 1112. Internal and external standards were run throughout, as well as separated N_2 and CO_2 references gases, using a Delta plus XL via a Conflo III interface. The analytical precision of carbon and nitrogen isotope analysis, based on instrumental error, is ± 0.2‰, 1 s.d.

3.2.3 Oxygen isotope analysis: geographical origins and residential mobility

Oxygen

Oxygen isotopes can either be obtained from the phosphate or carbonate fractions of bones and teeth. Phosphate ($\delta^{18}O_p$) values are considered to be less prone to diagenetic change, but because of difficulty with preparation and measurement of phosphate samples, carbonate oxygen values ($\delta^{18}O_{carb}$) will be the focus of this study (White et al. 1998; Sponheimer and Lee-Thorp 1999; Pellegrini et al. 2008; Pellegrini et al. 2011).

$\delta^{18}O_{carb}$ ($^{18}O/^{16}O$) values are measured relative to the international standard: Vienna Standard Mean Ocean Water (VSMOW). The oxygen isotopic composition of body water ($\delta^{18}O_{bw}$) and therefore bodily tissues, is largely dependent upon local, environmental water/ drinking water values ($\delta^{18}O_{dw}$) derived from meteoric water (rain and snow), or from recycled water (lakes, wells, or springs (White et al. 2004)). Values may also be influenced by “foreign” sources, such as glacial meltwaters or distantly sourced rivers (White et al. 2004). Other sources of oxygen are derived, to a lesser extent, from food and as molecular air. The body water value consequently reflects the balance between oxygen entering the body and that excreted as sweat, urine and as respired CO_2 (Prowse et al. 2007; Pellegrini et al. 2011).

Mammalian bones and teeth are formed in equilibrium with the body water, and therefore reflect the isotopic composition of this water at the time of their formation (Prowse et al. 2007). For this reason, it is possible to identify migrants to specific areas, as the ratio of $^{18}O/^{16}O$ can vary based on changes in temperature, elevation, evaporation conditions and distance from the sea (White et al. 1998; White et al. 2004; Prowse et al. 2007). These changes can reflect seasonal variation or movement around the landscape.

The use of dental enamel, which does not turnover or regenerate, provides a lasting record of the meteoric water ingested and other environmental conditions as explained above, which can then be attributed to a discrete age range (Prowse et al. 2004; Prowse et al. 2007).

More recently it has been argued that breastfeeding affects oxygen isotope value (Wright and Schwarcz 1998; White et al. 2004; Britton et al. 2015). This is because enamel samples are taken from the crown of the tooth, which forms during early to late childhood (AlQahtani et al. 2010). This enamel does not regenerate once formed and so values reflect oxygen composition of food and water consumed during this time range (Prowse et al. 2004; Prowse et al. 2007). Breastmilk has been found to be enriched in ^{18}O relative to local drinking water sources because of fractionation in the mother's body during milk synthesis (Wright and Schwarcz 1998; White et al. 2004; Britton et al. 2015). This can result in increased $\delta^{18}O_{carb}$ values obtained from the tissues of nursing infants, and consequently, this increased value can also be detectable in the tooth enamel of adults (Wright and Schwarcz 1998; White et al. 2004; Britton et al. 2015).

Other human activities including storing, boiling, stewing and brewing have also been shown to increase the oxygen isotope ratios of drinking water (Brettell et al. 2012). Brettell and colleagues were able to identify large shifts in $\delta^{18}O$ values under various experimental conditions including boiling water and cooking stews. These shifts in oxygen isotope ratios were related to isotopic fractionation occurring during evaporation. This, therefore, shows that human activity can significantly affect the $\delta^{18}O_{carb}$ values obtained from human remains. Consequently, it is important to interpret oxygen isotope data at a population level in order identify outliers, rather than comparing human $\delta^{18}O_{carb}$ values to that of expected $\delta^{18}O_{dw}$ values.

Conversion equations for oxygen isotope analysis

As the aim of oxygen isotope analysis was to explore regional human $\delta^{18}O$ values and to identify possible outliers, $\delta^{18}O_{carb}$ values have been investigated without conversion to drinking water values. This was done to avoid introducing increased error into the data set, which has been identified by previous studies into the application of conversion equations on oxygen isotope data (Pollard et al. 2011; Chenery et al. 2012; Britton et al. 2015).

To investigate relationships between human $\delta^{18}O_{carb}$ values from tooth enamel and modern rainwater samples, $\delta^{18}O_{carb}$ values were subsequently converted into $\delta^{18}O_{dw}$ (drinking water) values following the equation by Chenery et al (2012), based on Daux et al (2008), Equation 6. This equation allows for $\delta^{18}O_{dw}$ values to be directly estimated without converting them into phosphate ($\delta^{18}O_p$)

values first (Chenery et al. 2012). This was not done as a method of attributing specific geographical locations to individuals. For comparison with other studies, $\delta^{18}O_{carb}$ values have also been converted into $\delta^{18}O_{p}$ values following the equation by Chenery and colleagues (2012).

$$\delta^{18}O_{p} = 1.0322 \text{ X } \delta^{18}O_{carb} - 9.6849$$

Equation 1. Conversion from carbonate oxygen isotope ratios to phosphate oxygen isotope ratio estimates from Chenery et al. (2012)

$$\delta^{18}O_{dw} = 1.590 \text{ X } \delta^{18}O_{carb} - 48.634$$

Equation 2. Conversation from carbonate oxygen isotope ratios to drinking water estimates from Chenery et al. (2012)

Sample preparation and measurement of dental enamel for stable oxygen and carbonate

The measurement of enamel carbonate and oxygen isotope ratios is carried out simultaneously, and so the sample preparation for both techniques is identical. The number of samples taken from individuals buried at different cemeteries is presented in Table 3.7.

The tooth enamel was removed using dental burs and stored in plastic micro-tubes. To remove any remaining organic material, the powder was then agitated in NaOCl using a whirl mixer and then left for 30 minutes. Samples were then centrifuged and rinsed 3 times in deionised water, centrifuging between each rinse. To remove any diagenetic carbonate, an acetic acid solution was added and left for 10 minutes. A further 4 rinses were carried out with deionised water before each sample was frozen and freeze dried. ~2mg of enamel powder was reacted with 100% phosphoric acid at 70°C for 60 minutes in a Thermo Delta V connected to a Gasbench II, to produce CO_2. The precision of this analysis is also ±0.2. The analysis was undertaken at the University of Bradford stable isotope facility. Internal standards were run alongside samples to monitor measurement variation. These Internal standards were Merck (pure calcium carbonate, carbon: -34.45, oxygen: +13.35 VSMOW) and OES (ostrich eggshell, carbon: -10.72, oxygen: +25.45 VSMOW).

Oxygen Stable Isotope and enamel carbonate analyses	
Site	*Number*
Križna gora	25
Dolge njive	9
Sv Križ	4
Ljubljana Congress Square	5
Obrejze	6
Sv Petar Ludbreški	1
Zagorje ob savi	2
Grofove njive	4
Metlika	2
TOTAL	**57**

Table 3.7. Number of samples measured for enamel carbonate and oxygen Stable Isotope analysis.

This method of analysis was selected to address all three aims of this research. As many enamel samples as possible were taken from the non-cremated skeletal remains, to produce the largest possible regional scale data set. Where deciduous teeth were available, these were also sampled. However, it is recognised that these samples are not directly comparable with permanent tooth enamel samples, as they cover an early developmental stage, probably more influenced by breastfeeding and weaning (Wright and Schwarcz 1998; Britton et al. 2015). Instead, these deciduous tooth samples were taken to compare with paired permanent teeth, to assess the offsets between the two tooth types, which could provide evidence of, for example, weaning (Wright and

Schwarcz 1998; Wright and Schwarcz 1999; Britton et al. 2015). The sampling of tooth enamel was constrained by availability and included first and second molars, premolars, and very rarely permanent canines and incisors. The tooth type sampled from each individual are presented in Appendix

The permanent tooth samples were analysed to assess regional and site-scale isotopic variation. From this, themes of mobility, diet, gender and social structure were explored.

3.2.4 Strontium isotope analysis

Strontium isotope analysis of 15 tooth enamel samples (selected and taken by the author) was carried out at Durham University under the supervision of Dr Janet Montgomery, was used in conjunction with oxygen isotope analysis to investigate themes of geographical origins and mobility.

This method of isotope analysis is used as a means of determining childhood origins and residential mobility (Budd et al. 2000; Montgomery et al. 2007). It is dependent upon the variation in strontium isotope composition of local rocks and geology, with the addition of local rainfall and terrestrial aerosols (Budd et al. 2000; Montgomery et al. 2007; Montgomery 2010). The method investigates the relative abundances of ^{87}Sr and ^{86}Sr relative to NIST SRM 987 strontium carbonate standard (Budd et al. 2000; Slovak and Paytan 2012: 754).

Strontium is incorporated into the body as it can substitute calcium in the mineral phases of bones and teeth of humans and other mammals (Montgomery et al. 2007). This isotope ratio enters the body through the food and water that is ingested by an individual. Strontium is released from the local geology as rocks weather and erode, thus entering the biosphere. Plants take up this strontium from the soils and available water sources and, in this way, a local strontium isotope ratio enters, unfractionated, into the food chain (Montgomery 2010). The isotope ratio will subsequently reflect the geology, and therefore the place of residence of an individual at the time that tissue was formed (Montgomery 2010).

The concentration of strontium in body tissues, rather than the $^{87}Sr/^{86}Sr$ value, can vary in relation to processes in the body. There is no linear or direct route for strontium to be incorporated into bodily tissues and so the amount of strontium found throughout the body and between tissues can be highly variable (Montgomery et al. 2007; Montgomery 2010).

For this method to be effective, it is vital that biogenic strontium, i.e. the strontium incorporated into the tissues of an individual *in vivo*, is well preserved and unaltered (Budd et al. 2000). It has been found in previous studies of archaeological material that strontium in porous tissues, such as bone and dentine, is prone to diagenetic alteration, which includes both the addition of environmental strontium from the burial environment, but also in some cases, the wholesale replacement of biogenic strontium with strontium from the burial environment (Budd et al. 2000; Snoeck et al. 2015). Because of this likelihood of contamination, it has become common practice to sample the tooth enamel for analysis, as this tissue has been proven to be highly resistant to contamination (Snoeck et al. 2015). This provides a tight age range that can be attributed to a geology type, but it also means that values are restricted to the developmental period in which the enamel was formed, which is childhood.

Strontium isotope analysis has also been used as a way of investigating subsistence strategies. Montgomery *et al.* (2007) could identify differences in food attainment strategies of communities inhabiting the Yorkshire Wolds based on the varying strontium isotope values. Neolithic inhabitants displayed a wider than expected variation in $^{87}Sr/^{86}Sr$ values, which indicated that they were obtaining their food from a range of different geographical areas with different strontium sources. Moving into the Early Bronze Age, samples reflected $^{87}Sr/^{86}Sr$ values more indicative of a system incorporating strontium from two sources. This was reflected in the data as a linear alignment of points. From this, the authors could argue for a more sedentary lifestyle in the Late Bronze Age, with the possibility of a seasonal dietary system, or for crops grown in one location and animals grazed in another. It was also suggested that the linear array of values may indicate the movement of people between two discrete locations, or transhumance (Montgomery et al. 2007).

It is largely recognised that this method is a valuable tool for the identification of anomalous individuals, and therefore ‘non-locals’, but subsequently ascribing them a definitive place of residence is problematic (Montgomery 2010). This is particularly true in areas of complex geology, where similar values could be obtained from various sites, often in areas that are not far apart. Local human 'territories' may encompass a few different geologies and strontium sources, and so interpretation of mobility and immigration need to be made with care (Montgomery 2010). An example of this from the ENTRANS project would be the cemetery at Dolge njive and its associated hillfort of Vinji vrh, which was constructed on four different geological formations. Depending on where water sources were located, animals grazed, and crops grown, individuals from this location could give a wide range of $^{87}Sr/^{86}Sr$ values without anyone having moved any great distance.

This pilot study, analysing seven samples from Križna gora and eight samples from Dolge njive, has been carried out to address aims one and three. In combination with oxygen isotope analysis, this data is used to investigate themes of heterogeneity/homogeneity, subsistence strategies and geographical origins. Furthermore, as the first strontium isotope analysis of archaeological samples from the study area, to explore how the addition of this method would be advantageous to our understanding of the lifestyle of the communities inhabiting this region during the Late Bronze Age/Early Iron Age.

3.3 Statistics

Kruskal-Wallis ANOVA was applied to regional-scale data sets to establish whether there were any statistically significant differences between the isotope ratios obtained from apex dentine, rib or long bone collagen. This test was chosen over one-way ANOVA as it does not assume the normal distribution of data (Gray and Kinnear 2012: 260). Additionally, the unequal sample sizes between element categories were more likely to create error in a one-way ANOVA test, than a Kruskal-Wallis ANOVA test (Gray and Kinnear 2012: 260). The Kruskal-Wallis ANOVA tests for the equality of medians in the population (Gray and Kinnear 2012: 260). The significance value (asymptotic *p*-value) was 0.05 (Gray and Kinnear 2012: 260).

The Isotope ratios of deciduous teeth were not included in this analysis, as they are more likely to be influenced by breastfeeding and weaning (Millard 2000; Fuller et al. 2006; Beaumont et al. 2015). Consequently, these isotope ratios from deciduous teeth were more commonly identified as anomalies and would have skewed the results of statistical analysis. Statistical analysis was carried out using IBM SPSS Statistics 22 (Corp 2013).

As the poor preservation of skeletal remains was a limiting factor for the collection of osteological data (such as biological sex) and the number of graves investigated from each cemetery included in this study were consistently small and unrepresentative, inferential statistical analysis has not been carried out on either the osteological or the isotopic data at the site-scale. Descriptive statistics, such as means and interquartile ranges, have been used to explore and discuss trends identified within data sets, particularly regarding stable isotope data.

3.4 Additional analytical techniques

Additional analytical techniques have been carried out as part of the ENTRANS project. These datasets are also drawn upon where appropriate, to consider themes of homogeneity/heterogeneity and identity in the past.

The radiocarbon dating of 56 cremated bone and collagen samples (from humans and animals) was carried out by the Scottish Universities Environmental Research Centre (SUERC), to create a relative chronology between sites and to ensure the animal baseline constructed for carbon and nitrogen isotope analysis was largely contemporary with human remains.

aDNA analysis has been undertaken on 22 petrous bones of individuals from inhumation graves at Harvard University under the supervision of Professor David Reich. This latter analysis was carried out as part of a separate research project and, regarding the present research, permission was granted for the presentation of sex data. Detailed information regarding further results or the methods chosen for the analysis of aDNA samples was not available.

Strontium Isotope analysis of 15 tooth enamel samples was carried out at Durham University under the supervision of Dr Janet Montgomery. Consequently, explanations of sample preparation and measurement have not been presented in this thesis.

The sampling for all these additional analytical techniques, including collagen extraction for radiocarbon dating, was organised and carried out by the author.

Chapter 4 . Results of the osteological analysis of unburned human remains

The following chapter provides and briefly discusses the results of the osteological analysis of 91 sets of unburnt skeletal remains excavated from inhumation burials from across the ENTRANS study area. Although many of these sets of skeletal remains consisted of individual skeletons, some taphonomic and post-excavation issues have shown that this was not always the case. There are instances where skeletal remains appear to have become mixed post-burial, and cases where the context of some skeletal remains is not clear, for example, the cemetery of Grofove njive. These issues have been discussed in more detail below. Digitised copies of recording forms for each skeleton can be found in Appendix A, Disk 1.

As has already been addressed in Section 2.1.1, and in more detail in Section 4.1, the preservation of these skeletal remains was a major limiting factor for the collection of age and sex data. Many of the skeletal remains were in a very poor and incomplete condition. Most of the skeletons had undergone severe taphonomic change, which resulted in the loss of external cortical bone and joint surfaces. For this reason, many traits and elements diagnostic of age or sex were too damaged to be of any use.

In rare instances, preservation was such that pathological lesions survived the burial environment. These lesions were most commonly associated with joint surfaces. Any lesions associated with the cortical bone, for example, woven bone or plaques, is probably under-represented because of the poor preservation of pathological remains due to surface erosion and fragmentation

(Pinhasi and Bourbou 2007: 33-40; Brickley and Ives 2010: 13-14). These issues are addressed in more detail below.

The total results of the osteological analysis of inhumation graves from the ENTRANS study area have been tabulated and presented graphically, though this section of the thesis shall focus on the cemeteries of Križna gora, Dolge njive and Obrežje. This is because these three sites are used as case studies throughout the remainder of this work, especially regarding the stable isotope analysis. These results, therefore, provide background and context for later interpretations exploring themes of social structure, diet and chronology.

4.1 Overall preservation and condition of skeletal remains

The skeletal remains that do survive the burial environment of Slovenia are generally poorly preserved and incomplete. The two individuals recovered from north-east Croatia were in a better condition and more complete.

Many of the skeletal remains from the site of Grofove njive were collected whilst still in blocks of soil (for example, Figure 4.1). These were micro-excavated by undergraduate placement student, Frankie Wildmun, under the supervision of Dr Jo Buckberry. Once cleaned, it was clear that most of these skeletons had been destroyed in the burial environment and many could only be attributed to the category of “adult” via the identification of teeth. As these remains are known by their context numbers, rather than their grave or skeleton numbers (and consequently it is not known for certain which elements belong to which individual), they have been removed from some of the following investigations into frequencies of age and sex. These individuals were represented by 15 contexts and were less than 25% complete. Following their removal from further analyses in this chapter, 75 skeletons remain for further examination.

The skeletal remains included as part of the ENTRANS project were characterised by cortical exfoliation, root etching and water damage. Remains were commonly heavily fragmented. This was particularly the case for the less dense bones of the axial skeleton (vertebrae, sternum, ribs, and Ossa coxae) and crania, which were usually either incomplete or missing entirely. The dentition survived to varying degrees of preservation, but most frequently as loose teeth. An example of this can be found in Figure 4.2, depicting the surviving cranial fragments of Dolge njive, Grave 1775.

Figure 4.3 illustrates the level of completeness of skeletons from the ENTRANS assemblage (75), except for Grofove njive. As can be observed in this figure, over 50% of all the skeletons examined as part of this study fall within the <25% complete category. None of these skeletons was identified as being >75% complete.

Figure 4.1. Skull from Grofove njive. The skull was crushed and most of it remained inside a soil block

Figure 4.2. The surviving skull fragments from Dolge njive, Grave 1775

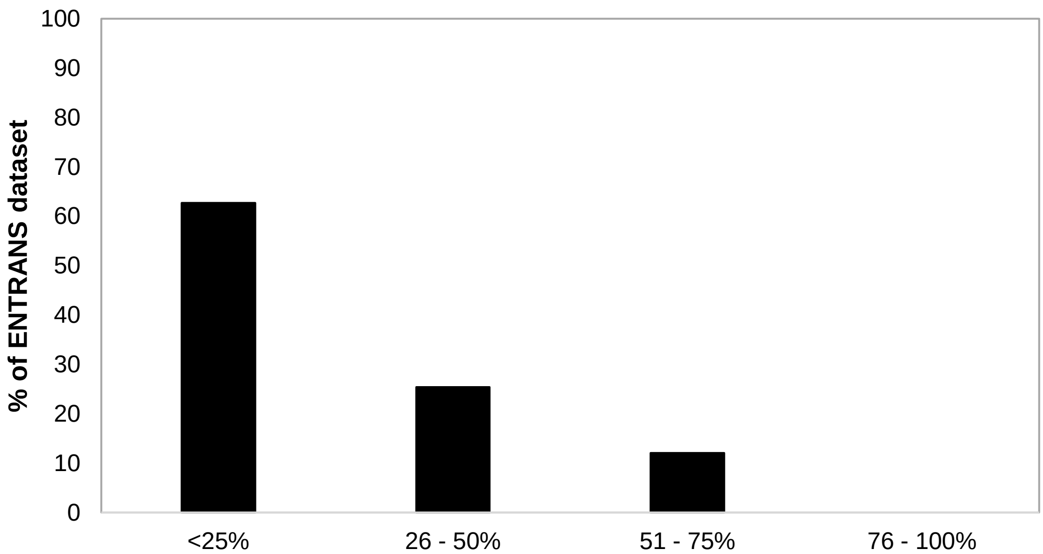


Figure 4.3. The frequency of different degrees of completeness. The y-axis represents the number of individuals from the whole ENTRANS inhumation data set, converted into a percentage. The cemetery of Grofove njive has been excluded. As the remains are only known by their small find numbers, it is unknown which elements belong to which grave. Though they have not been included in this figure, it is likely that each individual from this site is also <25% complete.

The skeletons examined from the cemeteries of Metlika/Hrib, Kapiteljska njiva were in a particularly poor state of preservation. The presence of incomplete third molars could rarely be used to indicate a younger individual, but overall, more accurate information regarding these individuals is limited.

This poor state of preservation is a vital consideration when approaching this assemblage. The high instances of skeletal destruction will have increased inconsistencies between the remains observed in the sample excavated and the demography of the original buried population (Stojanowski et al. 2002; Bello et al. 2006). Severe burial conditions have been shown to affect differential preservation patterns, with non-adult remains argued to survive less well than adult remains (Buckberry 2000; Bello et al. 2006), skeletons of elderly adults to be preserved less often than younger adult remains (Walker et al. 1988), female skeletons more prone to degradation than male skeletons (Walker 1995), and pathological remains to be preferentially destroyed above unaffected bones (Walker et al. 1988; Stojanowski et al. 2002; Bello et al. 2006). Additionally, partial excavations of cemeteries and incomplete collection of remains from graves can compound these biases. Consequently, in terms of palaeodemographic interpretations, this is a limited and biased sample.

4.1.1 Sv Petar Ludbreški, 1960

This middle adult male had additional taphonomic factors to consider. The skeleton exhibits areas of blackening (Figures 4.4 and 4.5), ranging from <1cm to the entirety of what remains of the parietals. This blackening has been interpreted as areas of exposure to heat. The distribution of these exposed areas is seemingly random, being identified on: both parietals; right temporal; mandible; blade of the right scapula; one thoracic vertebra; right proximal femur; right proximal tibia; left proximal tibia (within the medullary cavity)

The cause of this burning is unknown. The individual was found in an articulated, crouched position and so should have been at least partially fleshed when placed in the grave. This suggests that the bones were protected by muscle and connective tissue, making the accidental burning of the bones less likely. Alternatively, if the body of this individual had been exposed to heat, rather than being in a crouched burial position, perhaps they were buried in the pugilistic pose (see Section 10.1.2). This may have been the result of an unsuccessful cremation, were the soft tissue had failed to burn away, but where the heat had penetrated enough to char small parts of the skeleton.

Three Roman examples of skeletal remains, interpreted as failed cremations, have been described by McKinley (2008:199) from Baldock in Hertfordshire. In one particular example, there was charring to the elbows, knees and basal parts of the skull. Skeletal elements with little soft tissue coverage, such as the forearms and lower legs were white in areas, but there was no other evidence of burning across the remaining skeletons. The skeletal remains were found largely articulated in a simple grave cut, reminiscent of the male buried at Sv Petar Ludbreški (McKinley 2008b: 199). Unfortunately, due to the lack of excavation records, it is not known if there was any other evidence for the cause of this blackening, for example, charcoal in the grave pit.

Figure 4.4 Sv Petar Ludbreški 1960 with the distribution of blackening

Figure 4.5. Sv Petar Ludbreški 1960: blackening on cranial fragments

4.2 Sex assessment

The following section of the chapter presents the results of sex assessment through the application of osteological methods. Where possible, the results of aDNA analysis (undertaken at Harvard University under the supervision of Professor David Reich) have also been provided for comparison in Section 4.2.3. This latter dataset provides an indication of how accurate the sex osteological assessments were. This has been done individually for the assemblages from Dolge njive and Obrežje.

4.2.1 The whole ENTRANS data set

The results of sex assessment for the whole ENTRANS inhumation data set can be found in Table 4.1 and Figures 4.6 and 4.7. The most common category was unsexed, followed by possibly male, possibly female, non-adult (and therefore sex assessment was not applicable) and finally, male. As has already been discussed, the poor level of preservation was a major limiting factor when carrying out this investigation.

As demonstrated in Figure 4.6, most cases where an assessment could be made used cranial features only. The rare occurrence of pelvic features meant that methods, which are arguably the more reliable methods for sex assessment, (see Section 3.1.1) were not possible. In ~40% of cases where sex could be assessed, a combination of pelvis and crania-based methods could be employed.

These results indicate that burial within an inhumation cemetery in this study area was open to both males and females, though males were found to be more numerous. It can be argued, therefore, that internment in inhumation graves and inclusion in this burial rite was not solely based upon the biological sex of the deceased.

Sex	Osteology (No.)	Osteology (%)
F	0	0
F?	14	18
M	8	11
M?	16	21
UNSEXED	25	33
NON-ADULT	13	17

Table 4.1. Results of sex assessment for the whole ENTRANS inhumation assemblage following osteological analysis

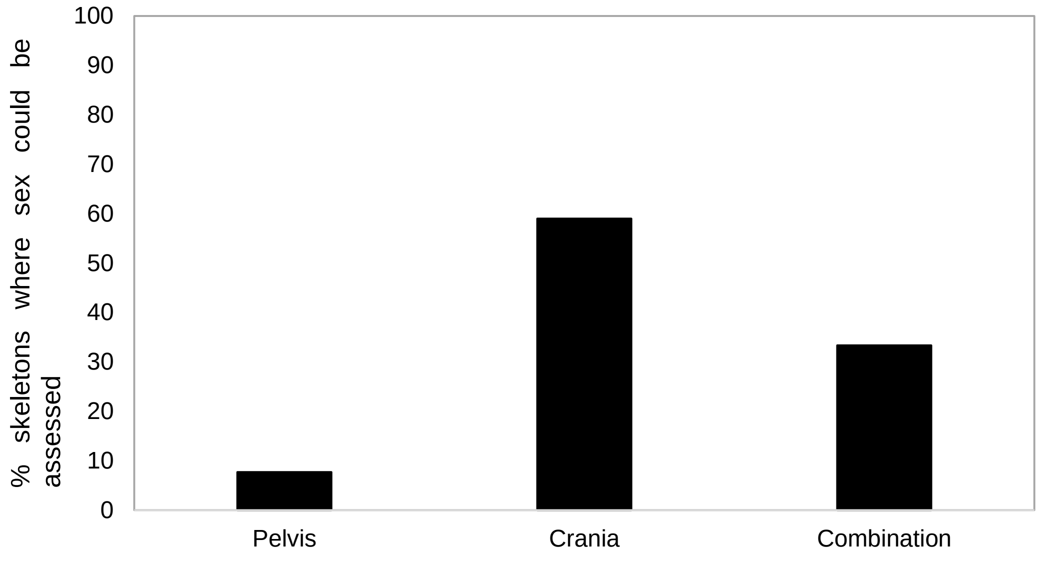


Figure 4.6. The frequency of diagnostic traits observed for the assessment of sex. The combination category relates to instances where both pelvic and cranial traits could be used together. The y-axis

represents the number of individuals from the whole ENTRANS inhumation data set that could be assessed for sex, converted into a percentage.

4.2.2 Križna gora, Dolge njive and Obrežje: sex assessment using osteological methods

The results of sex assessment of skeletons buried at the cemeteries of Križna gora, Dolge njive and Obrežje can be found in Table 4.2 and Figure 4.7. These cemeteries are explored in more detail below.

Križna gora	Sex	Number	%
	F	0	0.0
	F?	8	22.2
	M	3	30.0
	M?	10	27.8
	Unsexed	10	27.8
	Non-adult	5	13.9
	Total	**36**	
Dolge njive	F	0	0.0
	F?	3	33.3
	M	0	0.0
	M?	2	22.2
	Unsexed	4	44.4
	Non-adult	0	0.0
	Total	**9**	
Obrežje	F	0	0.0
	F?	0	0.0
	M	1	20.0
	M?	1	20.0
	Unsexed	1	20.0
	Non-adult	2	40.0
	Total	**5**	

Table 4.2. The results of sex assessment for the Križna gora, Dolge njive and Obrežje inhumation assemblages

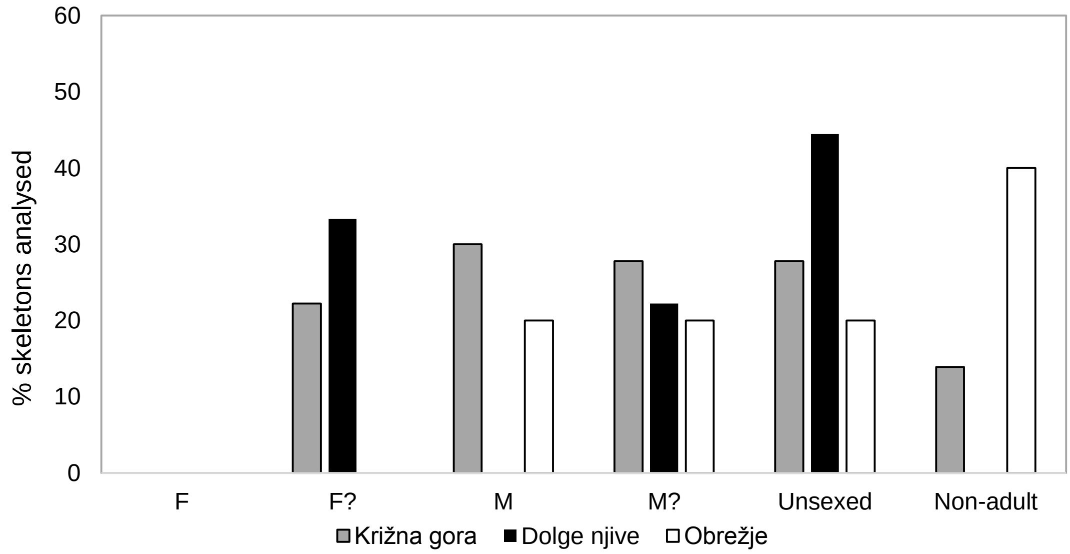


Figure 4.7 The results of sex assessment for the Križna gora, Dolge njive and Obrežje inhumation assemblages using osteological methods. The y-axis represents the total number of individuals in each sex-based category, converted into a percentage of individuals from each cemetery.

Križna gora

This assemblage is the largest group of individuals originating from the same cemetery included in this study (n=36). Although still not representative of the contemporary community, this larger group of individuals may provide a better insight into cemetery demographics than other assemblages, where only a couple of individuals have survived the burial environment. For this reason, Križna gora is used as a key case study throughout this thesis. Inventories, sex assessments and age estimations were carried out collaboratively by the author and Dr Hannah Koon due to time restrictions while analysing the assemblage. The skeletal collection was only available for analysis and sampling at the University of Ljubljana for less than two weeks.

13.9% of this assemblage were non-adult remains and, therefore, were not included in this sex assessment investigation (see Section 3.1.1). The percentages of other different sex-based categories are quite similar, ranging from 22.2% (possibly female) to 27.8% (unsexed). If the possibly male and male categories are combined, this equals 57.8% of the assemblage, which is more than double that of those assessed to be possibly female (there are no individuals assessed as female for this cemetery). However, it is difficult to argue whether this is a legitimate trend, with males more likely to be buried in this cemetery than females, or the result of other factors, such as bone survival and recovery rates. These percentages of male (?) and female (?) individuals support the argument made above that inhumation burial was not restricted or accessed by individuals based on biological sex alone.

Dolge njive

Because of severe taphonomic damage, many individuals buried at this cemetery could not be sexed using osteological methods (44.4%). Of the individuals that could be sexed, none of these assessments was definitive, with 33.3% possibly female and 22.2% possibly male. Again, these percentages are relatively similar to each other.

Obrežje

As has previously been discussed in Chapter 2, this site has an extended time depth, with burials dated to the Middle Bronze Age, Late Bronze Age, and the Iron Age. Subsequently, these skeletons represent perhaps the least representative group in terms of demography, relative to a local community. However, this unusual burial treatment has highlighted this assemblage as an interesting group and, therefore, this cemetery is repeatedly revisited throughout the thesis. For this reason, these remains have been addressed in more detail in this chapter.

When this assemblage was initially analysed utilising osteological methods, all the adult individuals were assessed as male, possibly male, or unsexed. These included the adults dated to the Late Bronze Age and the Iron Age. The two non-adults, one of which has been dated to the Middle Bronze Age (Grave 12623), were not included in this assessment.

4.2.3 Sex assessments using aDNA analysis

Alongside osteological methods of sex assessment, a random sample of twenty-one individuals from the cemeteries of Obrežje, Metlika/Hrib, Dolge njive, Ljubljana Congress Square, Zagorje ob Savi, Sv Križ and Kapiteljska njiva were submitted for aDNA analysis at Harvard University. This analysis was undertaken as part of another project led by Professor David Reich, who has allowed the ENTRANS project access to results.

These samples were selected based on the preservation of petrous bones. Information regarding the results of this analysis can be found in Tables 4.3 and 4.4. Here, the percentages of correct and incorrect sex assessments previously made using osteological methods can be found. Additionally, the percentages of previously unsexed and non-adult individuals, which have now been attributed a sex based on their aDNA, can also be observed. Out of the eleven skeletons that had been attributed to a sex (ten of which had been made at the level of "possible") based on osteological methods, 73% were correct. Where previous sex assessments had been made, but have been proven incorrect, these were all made at the level of possible male or female level, because of the poor levels of preservation and a dependency on cranial features (see Section 4.2.1).

Following aDNA analysis, the known sex of these twenty-one individuals can be used to further inform the number of individuals within each of the sex-based categories. This has been done in Figure 4.8. Following this combination of osteological and aDNA data, the general trends described above in Section 4.2.1, remain consistent. Both sexes are observed, with the percentage of females increasing and male individuals continuing to be more frequent.

Sex assessments	**Number**	**%**
Confirmed	7	32
Incorrect	3	14
Non-adult	2	9
Previously unsexed	6	27
Total	22	

Table 4.3. Percentages of sex assessments confirmed, incorrect or made following the application of aDNA analysis.

Site	*Skeleton (petrous bone)*	*Sex*
Metlika-Hrib	Gom I g35	Male
Dolge njive	1775	Female
Dolge njive	2603	Male
Dolge njive	2680	Male
Dolge njive	2903	Male
Obrežje	12623	Male
Obrežje	2544	Male

Obrežje	3043	Female
Grofove njive	279	Male
Grofove njive	272	Male
Ljublijana Kongresni Trg	1032	Female
Ljublijana Kongresni Trg	1029 A	Female
Zagorje ob Savi	grave 2	Female
Kapiteljska njiva	Gom I g16	Male
Sv Križ	Grob 1	Male
Sv Križ	Grob 3	Male
Sv Križ	Grob 6	Male
Sv Križ	Grob 9	Female
Sv Križ	Grob 10	Female
Sv Križ	Grob 11	Female
Sv Petar Ludbreški	1960	Male
	Gom = Tumulus	
	Grob = Grave	

Table 4.4. The results of sex determination from aDNA analysis for all individuals sampled

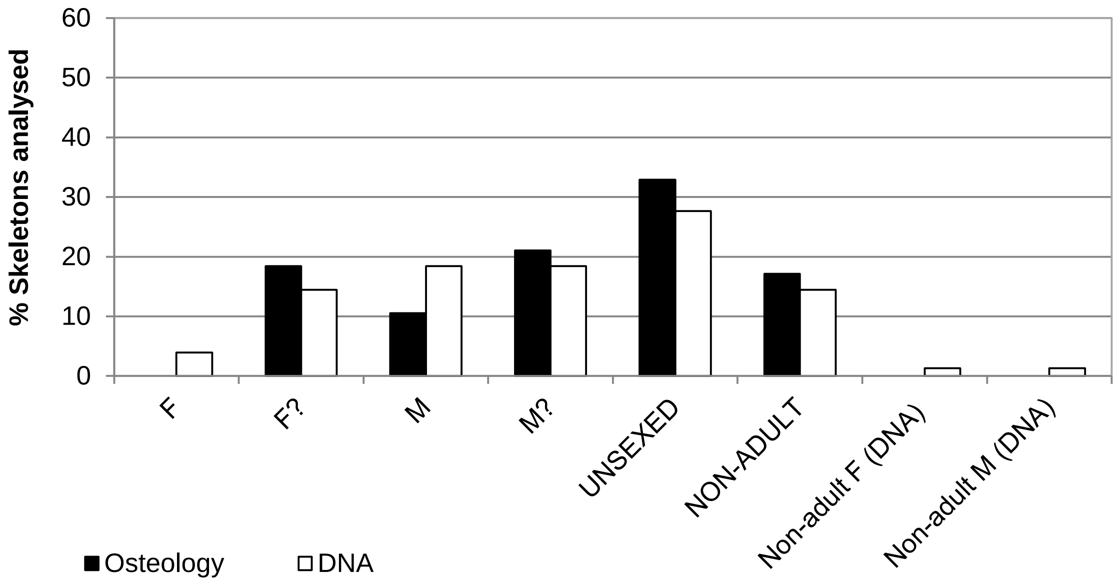


Figure 4.8. The results of sex assessment for the whole ENTRANS inhumation assemblage, combining osteological and aDNA analyses. The aDNA columns represent the altered distribution of sex following corrections with aDNA results.

Križna gora, Dolge njive and Obrežje: sex assessment using aDNA

As the sampling for aDNA analysis took place after the osteological analysis of human remains from Križna gora, at the University of Ljubljana, no petrous bones were available for this method.

From Dolge njive, the common survival of petrous bones in this assemblage meant that four of the nine skeletons could be sampled for aDNA analysis. The results of sex assessment using aDNA analysis can be found in Table 4.4. Here, the "unsexed" category refers to individuals who were not submitted for this analysis. These results show that at least one of the skeletons previously assessed as a possible female was a male. In the three cases where aDNA and osteological data could be compared, assessments made using osteological methods were correct. Additionally, one unsexed individual was identified as female.

In addition to sex assessments, the application of aDNA analysis of people buried at Dolge njive has revealed a genetic relationship between three individuals, who have been identified as siblings. The skeletal remains recovered from Graves 2603 and 2608 are of two brothers, while those excavated from Grave 1775 are that of their sister. This is an important discovery, as this aDNA link is the first definitive proof, from this study area, that individuals buried within tumuli were family groups. This familial relationship is explored later in this thesis when investigating strontium isotope analysis.

From Obrežje, when the aDNA data is compared to the osteological results, one of the skeletons previously assessed as unsexed was identified as a female. This is the individual buried with the vessel containing very fragmentary and incomplete human remains (Section 4.2.2, Figure 4.13). Following this comparison of aDNA and osteological data, all initial sex assessments based on osteological analysis were correct. Additionally, one of the non-adults (Grave 12623) could be identified as a male.

4.2.4 Summary of sex assessment

Overall, there is strong evidence to suggest that burial in inhumation cemeteries was not dictated based on the biological sex of an individual. If the results of aDNA analysis are used in conjunction with the osteological analysis, as has been done in Figure 4.9, then the percentages of males and females alter slightly compared with the use of osteological methods alone.

Both male and female remains were identified from most cemeteries, although percentages of male remains were usually higher. However, 44% of the individuals from the whole study area could not be assessed for sex using osteological or aDNA methods, because of the incomplete and poorly preserved nature of these skeletal remains. This has probably resulted in biased data.

The comparison with data from aDNA analysis has shown that there is some error within this dataset and that it should be used with caution. In most cases, sex assessments made using osteological methods have been attributed at the "possible" level because of poor preservation. However, comparing osteological and aDNA data has also shown that assessments made using observation-based methods were also generally effective.

When compared to the archaeological context, introduced in Section 1.2, these results corroborate with previous archaeological interpretations, where both female and male inhumation graves dating to the Early Iron Age have been previously identified based on object typologies.

4.3 Age estimation

4.3.1 The whole ENTRANS data set

The results of age estimation for all the cemeteries from the whole ENTRANS study area can be found in Table 4.5, Figures 4.10 and 4.11, and Appendix A, Disk 1.

Due to the incomplete nature of the remains, dental development (AlQahtani 2010) and tooth wear analysis (Brothwell 1981) were used most often. Consequently, although age estimates for non-adult individuals are likely accurate and precise, estimates for adults may be less so, as it was not possible to calibrate this method according to the local population (see methods). Auricular surfaces were identified in very rare cases and, consequently, the Buckberry-Chamberlain method could only be used on a case by case basis. Figure 4.10 provides information regarding the frequency of diagnostic traits used for age estimation. Evidence from more than one trait was used when possible.

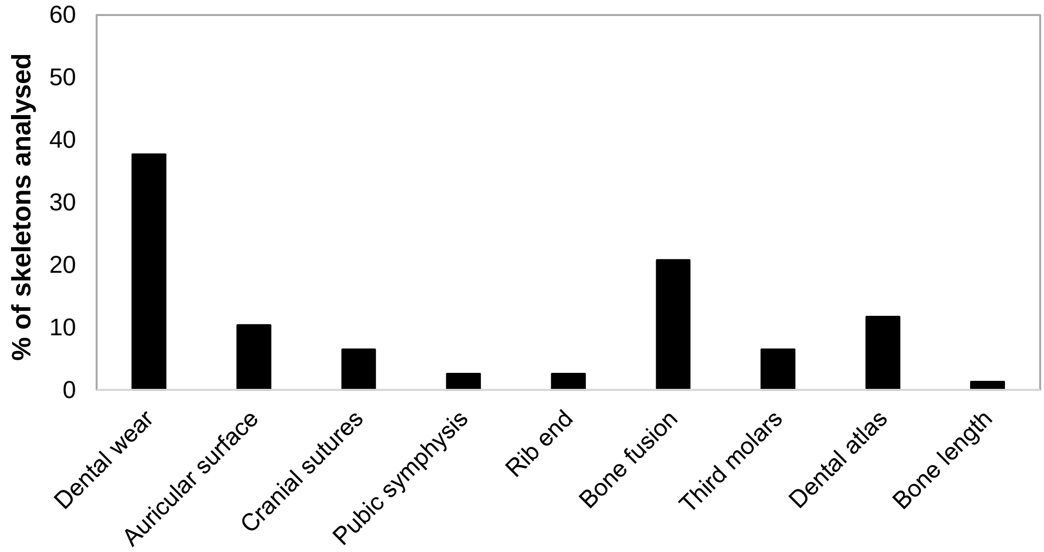


Figure 4.9. The frequency of diagnostic traits observed for age estimation. The y-axis represents the number of individuals which could be assigned an age range based on these traits, converted into a percentage of the whole ENTRANS inhumation dataset.

For non-adults, bone fusion could be used as supporting evidence in most instances. Late fusing epiphyses also aided identifying young adults. Because of the restrictions associated with these remains, it is likely that there is some overlap between young and middle, and middle and mature adults. Where none of the diagnostic traits have survived sufficiently to indicate biological age, but where size, robusticity and bone fusion have allowed, the category of "adult" has been used.

The results of age estimation using osteological methods for the whole ENTRANS data set can be found in Table 4.5 and in Figure 4.10. 33% of skeletons could not be assigned to a specific age range other than "adult". This was because of the infrequent survival and recovery of diagnostic traits, such as the auricular surface, cranial sutures, pubic bone, rib ends or late fusing epiphyses. Many of the following age estimations could only be made using dentition.

Age	**Number**	**%**
Non-adult	13	14.3
Young adult	17	18.7
Middle adult	29	31.9

Mature adult	2	2.2
Adult	30	33.0
Total	**91**	

Table 4.5. The results of age estimation for the whole ENTRANS inhumation grave assemblage

The middle adult category was the most prevalent across the different cemetery assemblages. This category covers the longest age span from c.36 to 50 years of age (see Section 3.1.1 for explanations of age ranges). Due to the inaccuracy of age estimation methods based on skeletal degradation, this category may also include individuals that were not part of this age range, but whose skeleton may have degraded faster or slower than others (Buckberry 2015). Therefore, it is not unusual for this age range to be the most common in archaeological assemblages (Buckberry 2015).

14.3% of individuals making up the ENTRANS inhumation dataset were non-adults. Non-adults were identified at almost every cemetery investigated as part of this study. The percentage of mature adults identified was comparably low (2.2%) relative to the middle adult and young adult categories. Initially, it would appear that people were commonly dying before reaching old age. However, it is more probable that mature adult skeletal remains were showing less evidence of, for example, joint surface destruction and were, therefore, more likely to be included in the middle adult category. The remains of mature adults have also been observed as more susceptible to damage in the burial environment (Walker et al. 1988). There is consequently a bias towards the remains of younger adults surviving in comparison to older individuals who could have had a decreased bone density (Stojanowski et al. 2002). This could be an explanation for the low numbers of mature adults identified from this study area, especially as remains from this region are already characterised as poorly preserved, with many skeletons destroyed prior to the excavation of their graves.

Overall, these results show that individuals from all age categories have been identified from cemeteries from this study area. This provides evidence for the argument that inhumation burial was not restricted or provided based on the age of the deceased.

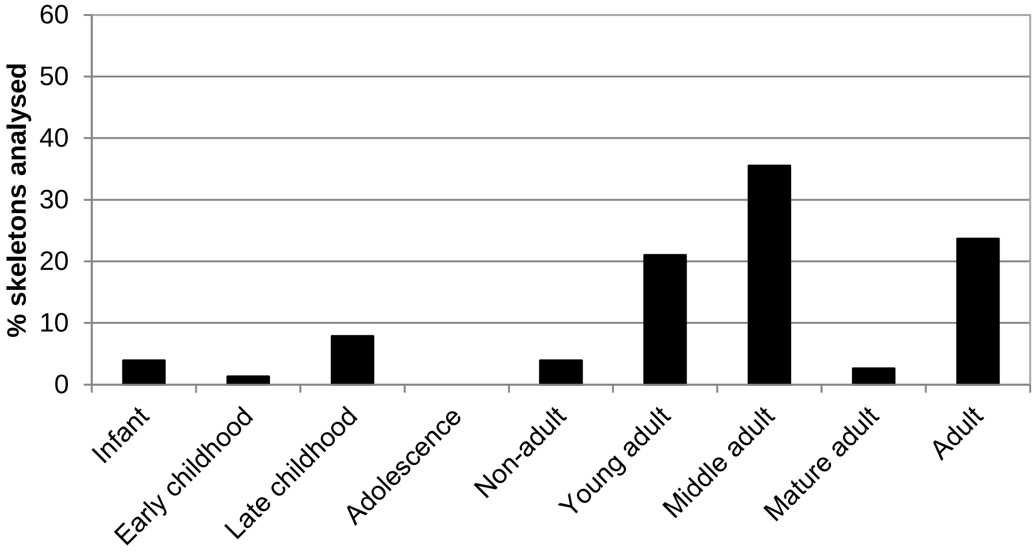


Figure 4.10. The results of age estimation for the whole ENTRANS inhumation assemblage. The y-axis represents the total number of individuals in each age range, converted into a percentage.

4.3.2 Križna gora, Dolge njive and Obrežje

The results of age estimation based on osteological analysis on individuals buried at Križna gora, Dolge njive and Obrežje can be found in Table 4.6 and Figure 4.11.

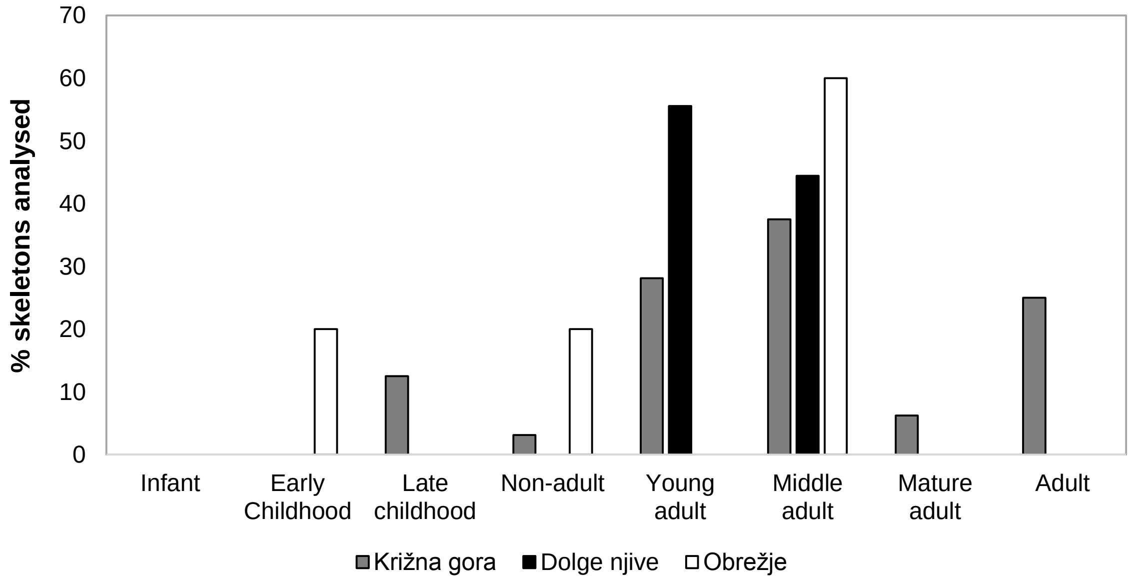


Figure 4.11. The results of age estimation for the Križna gora, Dolge njive and Obrežje inhumation grave assemblages. The y-axis represents the total number of individuals in each age range, converted into a percentage of individuals for each cemetery.

Križna gora

The results of this analysis for Križna gora (n= 32) are closely reflective of that of the whole inhumation data set. The most common category is that of Middle Adult, followed by Adult, Young Adult, Non-adult and finally, Mature Adult. This pattern also suggests that age group was not a restricting factor for burial in this cemetery.

Dolge njive

The individuals from Dolge njive (n= 9), conversely, are made up of a split of young and middle adults, with no non-adults or mature adults identified. This could either signify a more specialised location for the burial of specific individuals or that this assemblage has been heavily biased by preservation or recovery issues.

Obrežje

The remains from Obrežje (n= 5) are also problematic. Having radiocarbon dated these remains, it is likely that the two non-adults (at least Grave 12623) date to the Middle Bronze Age, whereas the Late Bronze Age and Iron Age Individuals fall broadly within the middle adult category. Due to the complex funerary context of this group of skeletons, very little can be said regarding age-based trends.

Križna gora	**Age**	**Number**	**%**
	Infant	0	0
	Early Childhood	0	0
	Late childhood	4	13
	Non-adult	1	3
	Young adult	9	28
	Middle adult	12	38
	Mature adult	2	6
	Adult	8	25
	Total	32	
Dolge njive	**Age**	**Number**	**%**
	Infant	0	0
	Early Childhood	0	0

	Late childhood	0	0
	Non-adult	0	0
	Young adult	5	56
	Middle adult	4	44
	Mature adult	0	0
	Adult	0	0
	Total	9	
Obrežje	**Age**	**Number**	**%**
	Infant	0	0
	Early Childhood	1	20
	Late childhood	0	0
	Non-adult	1	20
	Young adult	0	0
	Middle adult	3	60
	Mature adult	0	0
	Adult	0	0
	Total	5	

Table 4.6. The results of age estimation for the Križna gora, Dolge njive and Obrežje inhumation grave assemblages

Obrežje: curated remains

In addition to the five skeletons excavated at Obrežje, Grave 3043 also included a vessel containing very fragmentary and incomplete human skeletal remains (Figure 4.12). These remains were identified later in the project, following a final visit to the Institute for the Protection of Cultural Heritage of Slovenia, Novo mesto (Regional Office), in 2016. The remains consisted of 38.5g of bone fragments, mostly between 2-5mm in size. Following an examination by the author, it was noted that this small assemblage contained the remains of at least one adult and at least one non-adult. These were represented by a complete and worn, upper first incisor and a root of another complete, single rooted tooth. The adult remains also included maxilla and other cranial fragments (parietal and temporal). There were also fragments of adult (?) vertebral arches, the body of C1, plus a single rib fragment. There was also a fused head of an intermediate/proximal phalanx. The non-adult remains consisted of very fine rib and skull fragments. Additionally, the unfused epiphyses of either the hands or feet were present.

Figure 4.12. Human remains found in a small pottery vessel, deposited in Obrežje Grave 3043. The assemblage was found to include at least one adult and at least one non-adult.

These additional remains were of a poorer condition in comparison to the skeleton buried in grave 3043. The remains were heavily worn, with many fractured edges rounded, with a chalky texture. The incomplete nature and the worn appearance of these co-mingled remains suggest that this may be a curated assemblage. These individuals would have had to have been at least partially and probably fully skeletonised prior to collection and internment.

4.4 Paleopathology and trauma

Due to the poor preservation of the remains studied as part of the ENTRANS project, the identification of pathological lesions resulting in a diagnosis was relatively rare (7%). Pathological lesions were observed in 28% of the 76 skeletons examined (excludes Grofove njive). 11% were cases of joint disease or dense bone formation. Lesions such as plaques and woven bone were observed in 11% of individuals. Pathological lesions could have been more prevalent but were probably lost through the destruction of the cortical surface and bone elements, which was observed in most instances.

The following section of this chapter provides some examples of pathological lesions and trauma that were identified during the osteological analysis of skeletal remains from the ENTRANS study area. However, because of the poor preservation and unrepresentative nature of these remains, these cases cannot be used to interpret the health of these populations in any detail. Table 4.7 and Figure 4.13 provide some information regarding the types of pathological lesions observed across the ENTRANS assemblage. For the most part, individual lesions were identified on a skeleton, but a lack of supportive evidence meant that no further comments could be made regarding their aetiology.

Site	*Skeleton*	*Pathological lesions*
Dolge njive	2900	Compact bone
Sv Križ	11	Disc disease
		porosity
		compact bone
		Entheses
Ljubljana Congress Square	1029 A	Cribra orbitalia
		Sub-periosteal reaction
		Dental hypoplasia
	1032	Osteoarthritis
		Porosity
Zagorje ob Savi	2	Porotic hyperostosis
		Cribra orbitalia
		Compact bone
		Woven bone
	6	Osteophytes
		Striated woven bone
	Infant 1	Scurvy
		Non-specific infection
	Infant 2	striated woven bone

Sv Petar Ludbreški	1978	Peri-mortem fracture
	1960	Ante-mortem fracture
Križna gora	2	Cribra orbitalia (?)
	32	Porosity on crania
	63	Porosity on crania
	70A	Cribra orbitalia
	73	Osteoarthritis
		Disc disease
		Entheses
		Sub-periosteal reaction
	76	Porosity on crania
	77	Woven bone
	79	bone plaques
		Woven bone
	85	Expanded diploe
		Porosity on crania
	86	Head trauma (?)
Obrežje	12664	Cribra orbitalia (?)

Table 4.7. Pathological lesions identified during the osteological analysis of (76) inhumation burials from different cemeteries (excludes Grofove njive). The category of "other" consists of one case of expanded diploe from Križna gora (see Section 4.4.1). Some of these pathological lesions were observed in one individual. Where a diagnosis could be made, the pathological lesions consistent with the diagnosis have not been included in other categories. Pathological lesions were identified in 28% of 76 skeletons.

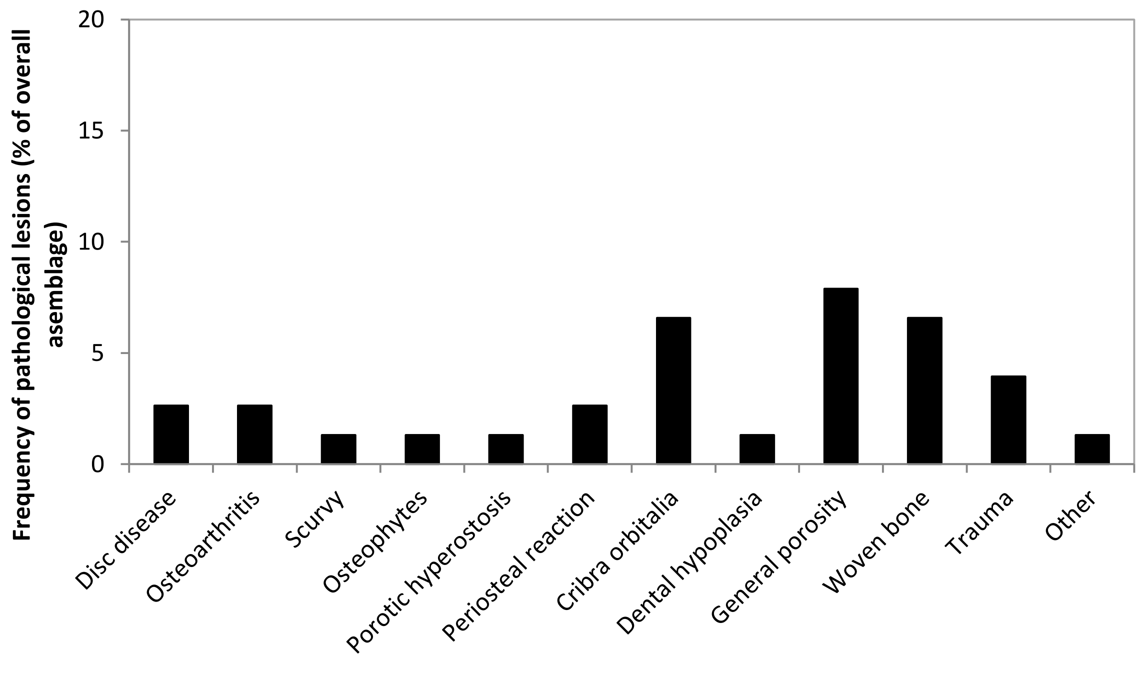


Figure 4.13 The pathological lesions observed and their frequency. Some of these pathological lesions were observed within the same individual.

4.4.1 Metabolic disease

As has already been addressed, pathological lesions commonly associated with metabolic diseases, which can affect the surface texture and morphology of skeleton, were not observed very often among these assemblages. This could indicate that conditions resulting in these lesions were not common within these communities. Alternatively, these lesions (especially lytic lesions) can result in these bones becoming more susceptible to destruction in the burial environment, especially when these burial conditions are already less than optimal (Pinhasi and Bourbou 2007: 31-40; Turner-Walker 2007: 24; Brickley and Ives 2010: 12-14).

Evidence of potential metabolic disease was most commonly observed as instances of cribra orbitalia, enamel hypoplasia and porosity across cranial fragments. However, there were rarely any cases where diagnoses could be reached, as supporting information, such as the spread of lesions across the skeleton or other associated lesions, was almost always absent (Weston 2008). For this reason, it was impossible to separate porous lesions symptomatic of metabolic conditions from, for example, infectious causes (Weston 2008).

One case of probable scurvy was identified from the cemetery of Zagorje ob Savi (Infant 1). This individual is discussed in more detail throughout this thesis, but specifically in Chapter 7. Another individual (Figure 4.14), buried at Križna gora (Grave 85) displayed an expansion in the diploe of their parietal bones, which, although not typical, could have been the result of a form of anaemia (Walker et al. 2009).

Figure 4.14. The parietal bones of the individual buried in Križna gora Grave 85. The diploe was observed to have thickened, which may have been related to a pathological condition, such as anaemia or infection.

4.4.2 Non-specific infection

As explained above regarding metabolic disease, the condition of the bones examined was probably such that non-specific infection was similarly almost never observed. One probable case has occurred alongside that of scurvy, observed in the remains of Infant 1, Zagorje ob Savi, and is further examined in Chapter 7.

4.4.3 Joint disease

Pathological lesions affecting the joint surfaces were the most commonly noted across the ENTRANS assemblage. This could be related to the osteoblastic nature of these lesions, such as osteophytes, which may have helped to preserve these bones (Stojanowski et al. 2002). These were usually noted in older individuals, such as Križna gora Grave 73, assessed to be a mature adult male. Figures 4.15 and 4.16 depict eburnation and porosity on the head of the femur, identified as osteoarthritis (Rogers and Waldron 1995: 26, 33-47; Ortner 2003: 545-558; Weiss and Jurmain 2007). The latter two figures show porosity of the faces of vertebral bodies, associated with osteophytes and fusion of the vertebral bodies (not seen in the lumbar vertebrae, and so not ankylosing spondylitis (Rogers and Waldron 1995: 67)), indicative of degenerative disc disease (Rogers and Waldron 1995: 66, 33-47).

From Ljubljana Congress Square, the middle adult female (assessed through aDNA analysis) similarly exhibited eburnation, osteophytes and porosity on the left articular processes of the lower cervical vertebrae, which are evidence of osteoarthritis (Ortner 2003; Weiss and Jurmain 2007). Further eburnation and osteophytes (indicative of osteoarthritis) were noted on the left articular processes of the upper thoracic vertebrae. Porosity, suggesting joint degeneration but not osteoarthritis, was also noted on the articular surface of the left acromio-clavicular joint (Ortner 2003; Weiss and Jurmain 2007).

Figure 4.15. Femoral head from Križna gora Grave 73, an example of osteoarthritis with porosity and eburnation

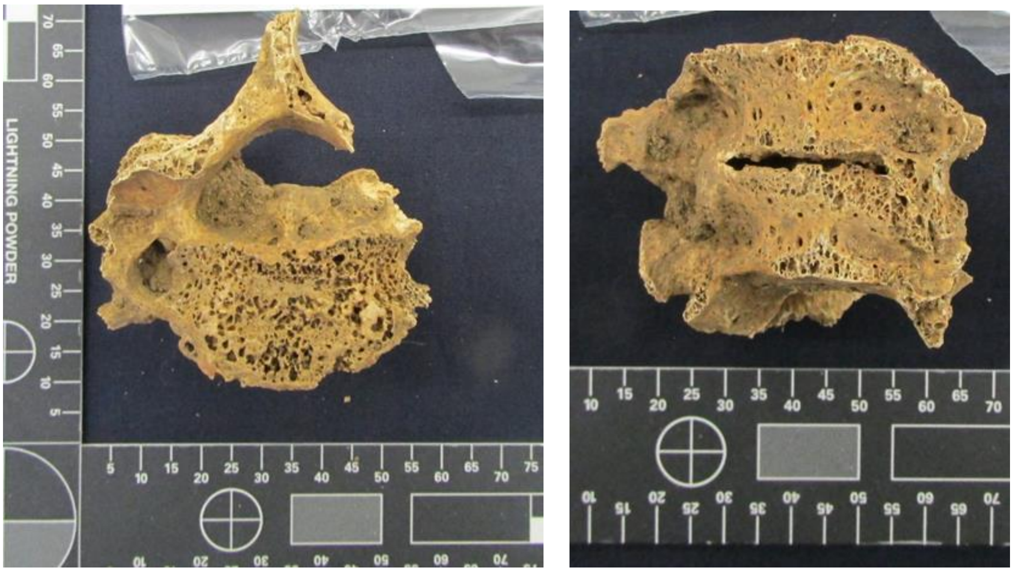


Figure 4.16. Vertebrae from Križna gora Grave 73. Contour change, porosity, osteophytes and fusion of osteophytes between vertebral bodies are evidence of degenerative disc disease

4.4.4 Trauma

<u>Križna gora</u>

There was a penetrating hole in the superior aspect of the parietal bones of the individual excavated from Grave 85 (Figure 4.17), with possible radiating fractures, though these appear jagged and rough, and are probably post-mortem, taphonomic damage (Berryman and Haun 1996). Bone appears to have been lost as flakes from the interior table of the parietal bone around the edge of the perforation (Berryman and Haun 1996). From the appearance of the perforation, this is a possible case of blunt force head trauma.

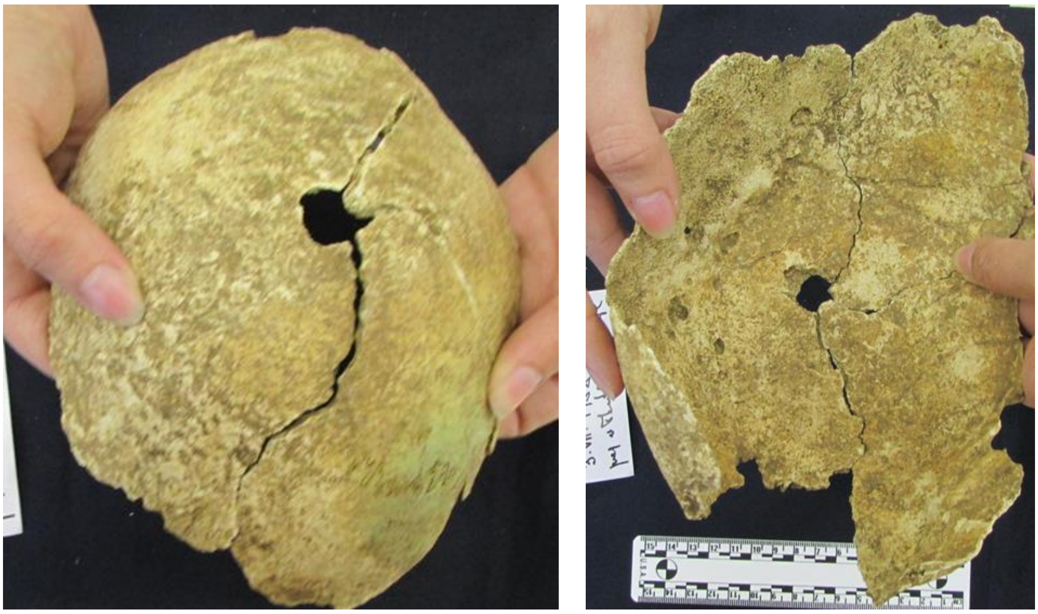


Figure 4.17. The parietal bones of the individual buried in Križna gora Grave 85. The perforation, radiating fractures and flaking from the internal border of the hole may be evidence of perimortem head trauma.

Sv Petar Ludbreški

Trauma was also noted on the femora of both the middle adult males from this site. These fractures have been presented in Figure 4.18. The right femur of the individual excavated in 1960 exhibits a united and well healed antemortem fracture to the proximal third of the diaphysis. This has caused an anterio-medial displacement of the neck and head. The malalignment of the femur would have caused a slight shortening of the limb, which would have probably led to a limp. The bone has not atrophied, and no other asymmetry was noted, suggesting that this individual continued to use the limb. The male excavated in 1978 has evidence of a perimortem fracture to the proximal third of the diaphysis of the left femur, inferior to the greater tuberosity. No other fractures were observed on either of these skeletons.

These fractures were probably caused by blunt force trauma, which may or may not have been accidental. The identification of femoral fractures is rare in the archaeological record because of the force required to fracture this robust bone. Fractured femora are more frequently noted in children and mature adults, in particular, post-menopausal females where the bone structure has weakened (Astrom et al. 1987; Judd and Roberts 1998; Judd and Roberts 1999). In modern times, fractures to the femoral shaft in young and middle adults are more commonly associated with high-energy trauma, such as road accidents, which result in a severe direct or indirect force to the limb (Lovell 1997; Weiss et al. 2009). The identification of two femoral fractures from two middle adult males is, therefore, interesting, as they are arguably less likely to have occurred in prehistory.

Figure 4.18. Two femoral fractures: A: Sv Petar 1978. Peri-mortem fracture to the proximal third of the diaphysis of the left femur. There is no evidence of healing. B: Sv Petar 1960. Well healed, but badly aligned ante-mortem fracture to the proximal third of the diaphysis of the right femur. Additionally, the blackened bone can also be observed, which may have contributed to the flaking of the cortical bone in this area.

4.4.5 Paleopathology overview

From this small sample of individuals, evidence for joint disease, metabolic disease and trauma has been observed from the sites of Križna gora, Ljubljana Congress Square, Zagorje ob Savi and Sv Petar Ludbreški. However, for the most part, there appears to be little surviving evidence of diagnosable, chronic skeletal disease across the sample. This does not necessarily mean that disease was rare. As has already been addressed, the preservation of these remains was poor, and so any evidence of paleopathology may have been destroyed in the burial environment. Furthermore, the concept of the osteological paradox must also be considered. The lack of evidence of disease does not mean that this population was necessarily healthy (Wood et al. 1992; DeWitte and Stojanowski 2015). For example, individuals who did show evidence of pathological conditions were able to survive long enough for bone changes to take place, indicating the potential to fight off illness and infection (Wood et al. 1992; DeWitte and Stojanowski 2015). This concept shall be considered in more depth in Section 10.3.

4.5 Summary of osteological analysis

- Bone preservation was a key limiting factor for osteological analysis
- Both males and females were buried in Inhumation cemeteries
- Individuals have been attributed to all possible age categories
- Inclusion in inhumation cemeteries was not dictated solely based on age or sex
- Evidence of diagnosable chronic disease was rare, but pathological lesions were recognisable in 28% of individuals

Chapter 5 The results of the osteological analysis of cremated human remains

The results of the osteological analysis of 248 cremation graves are presented below. The cemetery sites of Kaptol (n=21), Kapiteljska njiva (n=60) and Ljubljana SAZU (n=162) form the focus of these results, though other much smaller assemblages can be found in Appendix B, Disk 1.

Due to taphonomic damage and the absence of diagnostic features of the cranium and pelvis, the assessment of sex was found to be extremely difficult (<1%). Broad distinctions between adults and non-adults were frequently possible, and both categories were present in almost all assemblages. Figures 5.1, 5.2 and 5.3 are examples of typical cremation deposits from Kapiteljska njiva, Kaptol and Ljubljana SAZU.

Figure 5.1. Kapiteljska njiva gave 275 divided by sieve fraction (2mm, 5mm and 10mm)

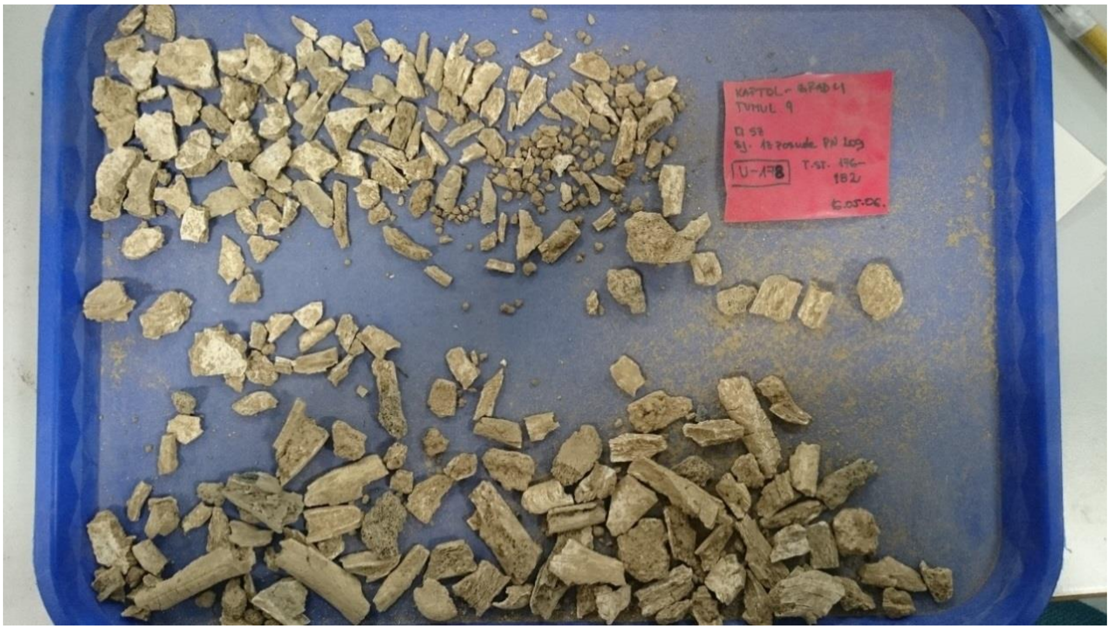


Figure 5.2. Kaptol Tumulus 9

Figure 5.3. Ljubljana SAZU grave 174 roughly sorted by skeletal region

5.1 Cremated remains: weights and fragment size

Limitations to the analysis of the cremated bone were the fragment size of the remains and generally low cremation weight (see Table 5.1 and Figure 5.4). These had a significant effect on the percentage of identifiable bone. Identified bone weight included animal bone, which was not identified to species in most cases, but which was recognised as non-human. As seen in Figure 5.5 and Table 5.2, the percentage of identified bone was notably higher in the assemblages from Ljubljana SAZU (n=167) than from Kaptol (n=21) or Kapiteljska njiva (n=60). When the average fragment sizes were considered, it was found that this was probably due to the higher proportions of bone from Kaptol found in the 5mm and 2mm sieve fractions.

5.1.1 Total weight

The overall weights of recovered cremated bone ranged from <10g to >13kg from a single grave deposit. These weights included fragments of human, animal and unidentified bone. Most cremation graves from all three cemeteries contained less than 500g of skeletal remains. The most frequent category for overall weights for cremation graves was 11 to 100g.

%													
Weight ranges (g)	**0-10**	**11-100**	**101-200**	**201-300**	**301-400**	**401-500**	**501-600**	**601-700**	**701-800**	**801-900**	**901-1000**	**>1000**	**>10,000**
Kaptol	0	40	0	10	5	5	0	0	5	5	5	15	10
Ljubljana SAZU	4	28	28	14	13	5	2	2	1	1	0	2	0
Kapiteljska njiva	20	36	12	8	8	0	7	2	3	2	0	2	0

Table 5.1. Percentage of cremation deposits in different total weight ranges (including animal bone) for Kaptol (n=21), Kapiteljska njiva (n=60) and Ljubljana SAZU (n=167).

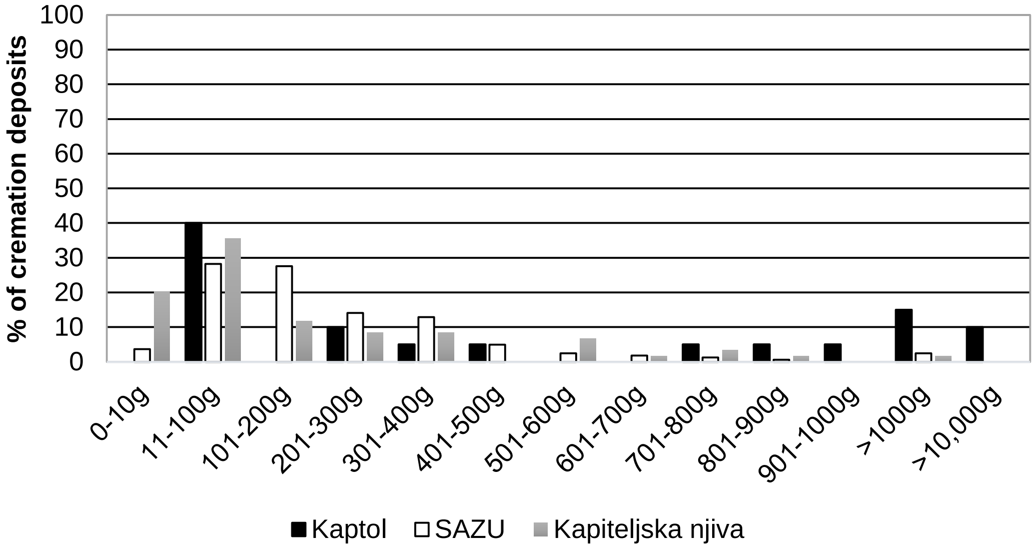


Figure 5.4. Percentage of cremations in total weight ranges for Kaptol (n=21), Ljubljana SAZU (n=167) and Kapiteljska njiva (n=60). For example, 40% of cremation deposits from Kaptol fall within the 11-100g total weight category (including animal bone).

There were cases from all three cemetery sites where total bone weight exceeded 1kg. Mckinley (1993) surmised from modern crematoria data that a fully cremated and complete adult body weighs 1001.5g – 2422.5g, with a mean of 1625.9g. This weight range occurred most frequently in the Kaptol assemblage, but, as illustrated in the bone element representation section below (Section 5.2), this site also produced the highest quantities of cremated animal bone. Animal bone was also noted in graves from Ljubljana SAZU and Kapiteljska njiva. Furthermore, ~11% of deposits from Ljubljana SAZU had evidence of multiple individuals from a single grave. For this reason, bone weight is not being used as an indicator of a complete individual in a grave deposit. Nonetheless, based on weight, it is likely that most individuals were only partially collected for deposition following the cremation process. It is unlikely that taphonomic process alone would be responsible for the loss of so much cremated bone.

5.1.2 Identified weight

	<10 %	10-19%	20-29%	30-39%	40-49%	50-59%	60-69%	70-79%	80-89%	90-100%
Kaptol	0	15	40	25	5	5	5	0	0	0
Ljubljana SAZU	0	1	2	1	13	17	24	21	10	7
Kapiteljska njiva	8	10	24	17	10	14	3	8	0	3

Table 5.2. Cremation deposits from Kaptol (n=21), Kapiteljska njiva (n=60) and Ljubljana SAZU (n=167) (% of each cemetery), separated by weight of identified bone fragments (% of cremation total weight). For example, 15% of cremations from Kaptol fall within the category of 10-19% of bone identified.

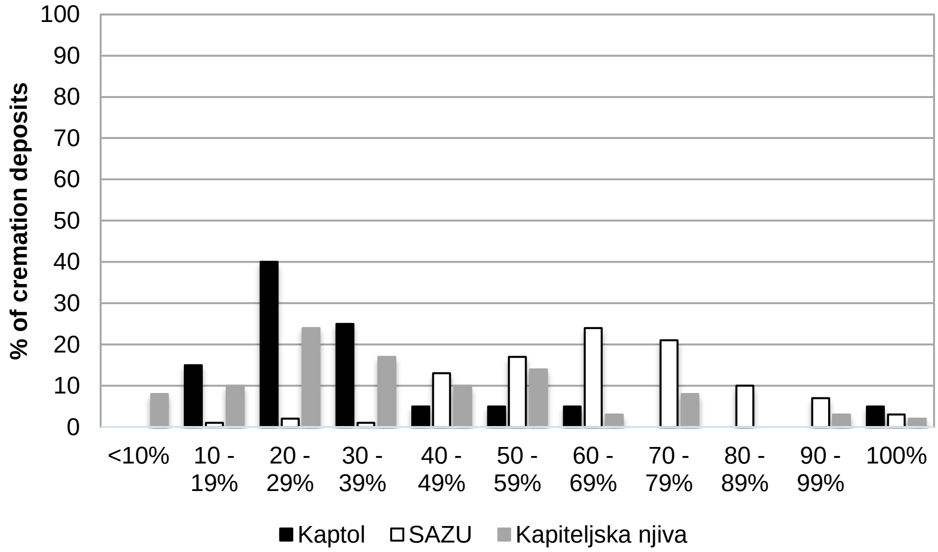


Figure 5.5. The percentage of identified bone (% of overall cremation weight) of cremation deposits from Kaptol (n=21), Kapiteljska njiva (n=60) and Ljubljana SAZU (n=167). For example, for 40% of cremation deposits from Kaptol, between 20 and 29% of bone could be identified.

5.1.3 Fragment size

Information regarding the fragment size of cremated remains can be found in Tables 5.3 and 5.4, Figures 5.6 to 5.9 and in Appendix B Disk 1. Overall, cremated remains from Ljubljana SAZU were more likely to be within the 10mm sieve fraction, whereas remains from Kaptol and Kapiteljska njiva had a higher frequency of remains falling into the 5mm and 2mm sieve fractions. Many of the larger fragments identified from the Kaptol assemblage were identified as animal bone, with horse and medium-large mammal bone very common from the heavier weight deposits. The high quantity of bone fragments within the 2mm and 5mm sieve fraction demonstrates the poor condition of the bone analysed, as well as the reduced potential for retrieving informative data. It is very unlikely that this cremated bone was as fragmented when it was originally deposited. The material from Kaptol was heavily damaged by the collapse of stone burial chambers under the weight of earthen mounds (H. Potrebica pers comm. 2016). It has also been widely reported that, while micro excavating cremated bone from burial urns, bone fragments which would have been originally intact had a tendency to disintegrate once removed from the support of the surrounding soil (McKinley 2004; Harvig 2015; M Črešna pers. comm. 2016). Consequently, the high level of fragmentation observed from these cemeteries is unlikely because of the cremation process and more likely linked to taphonomy.

Mean frag. Size	%10mm	%5mm	%2mm
Kaptol	53	31	9
Ljubljana SAZU	86	12	2
Kapiteljska njiva	34	57	9

Table 5.3. The percentage of cremated bone (by weight) found in the 10mm, 5mm and 2mm sieve fractions, giving a representation of overall fragment size frequency for the cemeteries of Kaptol (n=21), Ljubljana SAZU (n=167) and Kapiteljska njiva (n=60)

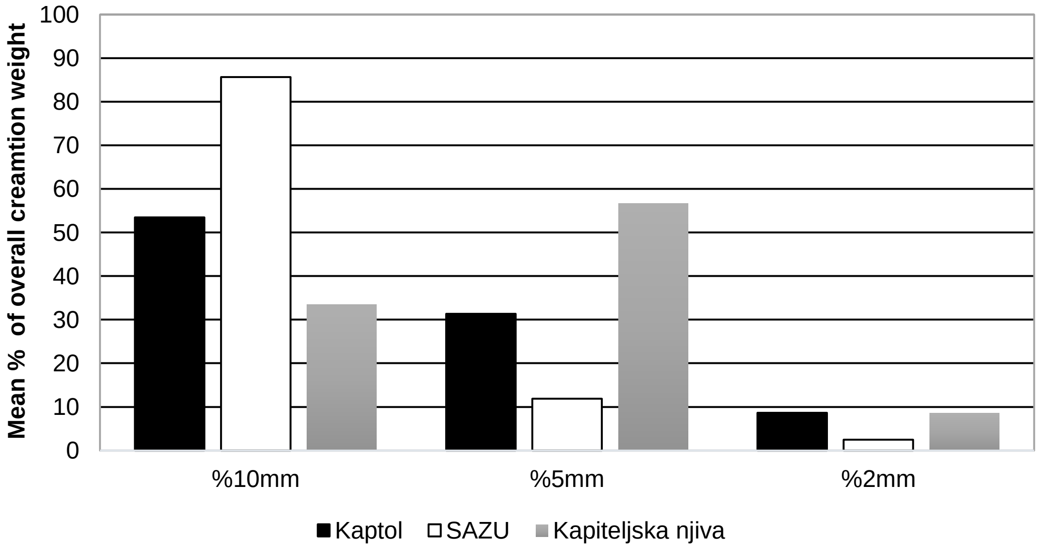


Figure 5.6. Mean fragment size, by bone weight, for Kaptol (n=21), Ljubljana SAZU (n=167) and Kapiteljska njiva (n=60). For example, 53% of cremated bone from Kaptol was identified in the 10mm sieve fraction.

Fragment size frequency	10mm sieve fraction			5mm sieve fraction			2mm sieve fraction		
	Ljubljana SAZU (%)	Kaptol (%)	Kap. njiva (%)	Ljubljana SAZU (%)	Kaptol (%)	Kap. njiva (%)	Ljubljana SAZU (%)	Kaptol (%)	Kap. njiva (%)
0	0	0	7	11	0	2	10	0	18
<10%	0	5	8	44	5	2	87	80	53
10 - 19%	1	10	17	28	15	3	3	5	15
20 - 29%	0	10	17	8	30	3	1	5	10
30 - 39%	1	0	15	6	20	8	0	5	2
40 - 49%	2	10	17	1	20	17	0	5	2
50 - 59%	3	20	7	1	10	7	0	0	0
60 - 69%	8	15	5	0	0	5	0	0	0
70 - 79%	9	15	3	1	0	3	0	0	0
80 - 89%	21	10	2	0	0	2	0	0	0
90 - 99%	46	5	2	0	0	2	0	0	0
100%	10	0	2	0	0	3	0	0	0

Table 5.4. Frequency of bone fragment size: the percentage of cremation deposits from each cemetery, divided by % total weight into sieve fraction. Cremation deposits from Kaptol (n=21), Kapiteljska njiva (n=60) and Ljubljana SAZU (n=167). For example, 5% of cremation deposits from Kaptol had <10% of their weight in the 10mm sieve fraction.

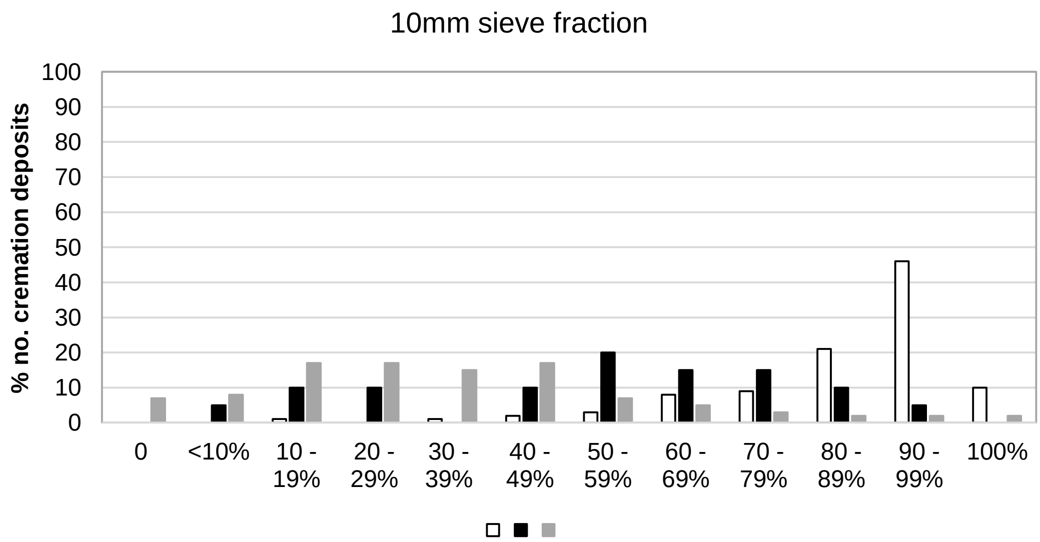


Figure 5.7. Fragment size frequency by bone weight (% of total cremation weight) for Kaptol (n=21), Ljubljana SAZU (n=167) and Kapiteljska njiva (n=60). 10mm. For example, 5% of cremation deposits from Kaptol had <10% of their weight in the 10mm sieve fraction.

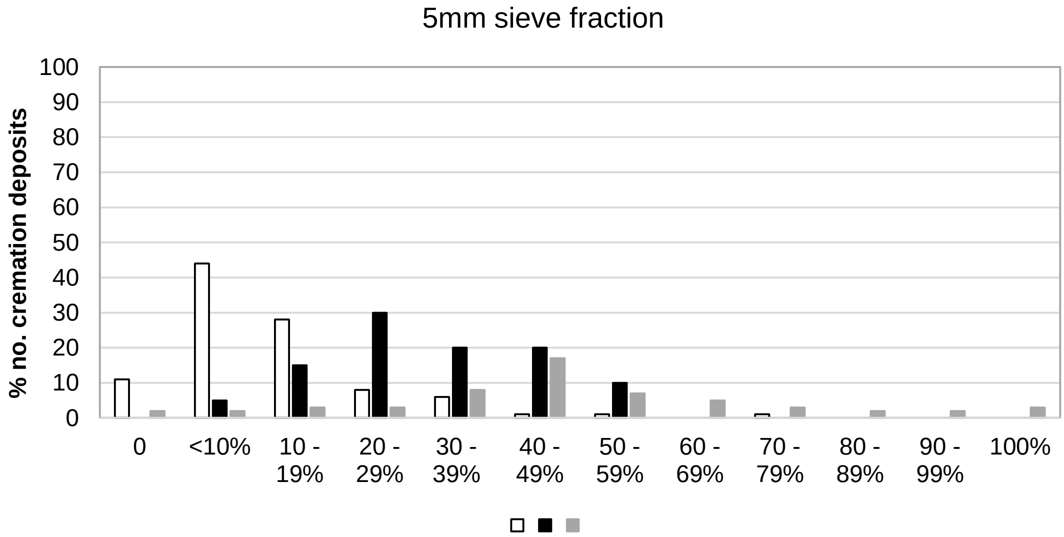


Figure 5.8. Fragment size frequency by bone weight (% of total cremation weight) for Kaptol (n=21), Ljubljana SAZU (n=167) and Kapiteljska njiva (n=60). 5mm. For example, 5% of cremation deposits from Kaptol had <10% of their weight in the 10mm sieve fraction.

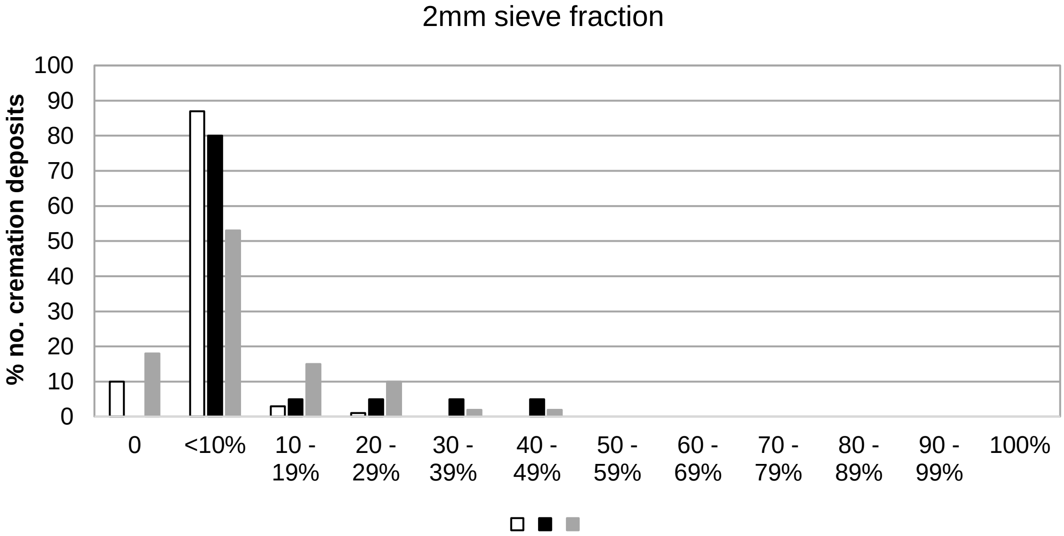


Figure 5.9. Fragment size frequency by bone weight (% of total cremation weight) for Kaptol (n=21), Ljubljana SAZU (n=167) and Kapiteljska njiva (n=60). 2mm. For example, 80% of cremation deposits from Kaptol had <10% of their weight in the 10mm sieve fraction.

The combination of low cremation weight and small fragment size across all the cremation deposits analysed as part of the ENTRANS project has significantly impacted on age estimation and sex assessment, as the diagnostic traits required for these analyses were, for the most part, absent.

5.2 Cremated remains: human bone element representation

To explore and compare relative bone representation within and between cremation deposits, the overall weight of bone fragments found within each skeletal category (skull, axial etc.) was recorded for each cremation deposit. To make this weight comparable between deposits and cemeteries, this was subsequently converted into a percentage of the identified weight of each cremation deposit. For example, Kaptol Tumulus 1 had an identified weight of 178.3g, 37.2g of which was skull fragments. Converted into a percentage, 20.7% of the identified weight of this cremation deposit was skull fragments. Following these calculations, a mean percentage of identified weight was calculated for each skeletal region, for each cemetery. This has allowed for the rapid comparison of bone element representation between cemeteries, which is tabulated in Table 5.5 and shown in Figure 5.10.

Mean % of total identified weight	% Skull	% Axial	% Upper limb	%Lower limb	% Animal bone	% Not bone	% Unburnt
Kaptol	31.2	3.5	10.2	9.0	41.4	7.3	0.0
Ljubljana SAZU	36.2	6.3	13.3	41.3	1.5	0.4	0.2
Kapiteljska njiva	60.7	2.9	7.3	21.8	0.1	4.2	0.0

Table 5.5. The mean of total identified bone weight (% of individual cremation deposits) separated by skeletal region. Kaptol (n=21), Ljubljana SAZU (n=167) and Kapiteljska njiva (n=60). For example, 31.2% of the identified bone (by weight) from Kaptol was made up of Skull fragments

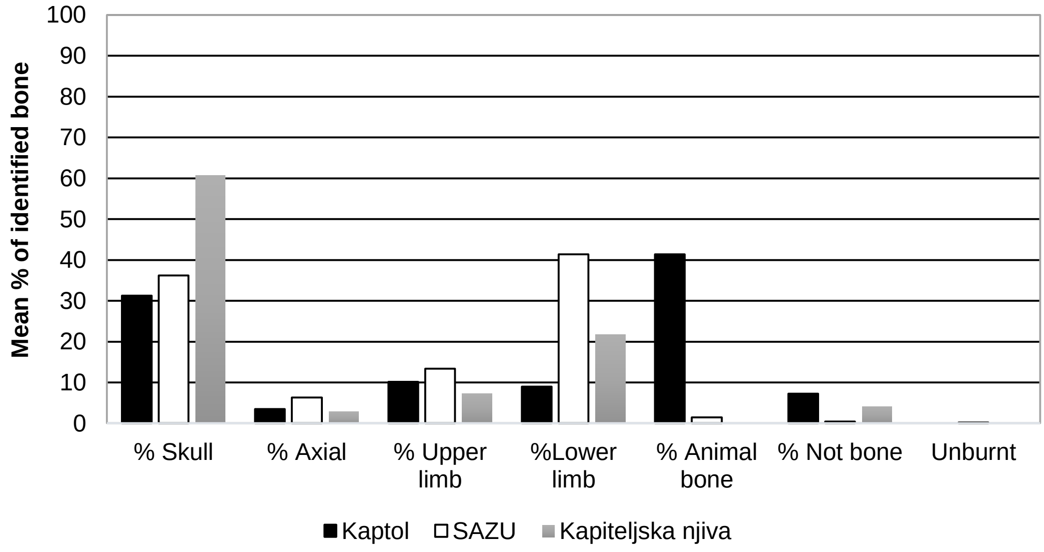


Figure 5.10. Bone element representation for Kaptol (n=21), Ljubljana SAZU (n=167) and Kapiteljska njiva (n=60). For example, for cremation deposits from Kaptol, the mean percentage for skull fragments was 31% of identified bone.

The most common skeletal elements identified from all three cemetery sites were skull fragments. This is to be expected as elements of the skull (crania, mandible etc.) are probably the easiest of the bone elements to positively identify. The lower limb was well represented by femur and tibia fragments, and to a lesser extent, fibula fragments. Animal bone was very common in cremation graves from Kaptol and was also identified in the Ljubljana SAZU and Kapiteljska njiva assemblages. The presence of high quantities of animal bone in the Kaptol assemblage created an additional layer of complexity to the analysis, as extra caution was taken when identifying long bones. This is perhaps one cause for the lower percentages of identified remains in comparison to the Ljubljana SAZU assemblage.

The axial skeleton was the least frequent category identified. This may have been due to taphonomic factors, with larger, thicker long bones more likely to survive the burial environment than, for example, ribs, which could be more susceptible to destruction and/or fragmentation (McKinley 2004).

Overall, the bone elements most commonly identified were the skull and larger long bones (e.g. the femur). This could have been linked to a selection process prior to burial, where larger pieces of the skeleton may have been preferentially selected (McKinley 1993; Williams 2004; Williams 2013). However, any interpretations regarding this should be treated with caution. The low overall bone weight, in addition to the high level of fragmentation of many of the remains, has led to difficulty in positively identifying elements.

5.2.1 Animal bone and evidence of other inclusions

During the analysis of the remains, high quantities of animal bone were noted (Table 5.5, Figure 5.10). This included cattle, horse, sheep/goat and dog, fish (Ljubljana SAZU) and goose (Kapiteljska njiva). The identification of these species (with the assistance of Clare Rainsford) provided further evidence for elaborate funerary practices, as all this animal bone was fully oxidised/cremated, rather than cooked. This was primarily noted in remains from Kaptol, but also at the earlier cemeteries at Ljubljana SAZU and Kapiteljska njiva, but at a much lower frequency.

The presence of tail bones, teeth, cranial fragments, vertebrae and long bones could suggest whole animals were burnt with the human body as part of the funerary practice (Figure 5.11). The identification of fully cremated and worked animal bone, including a perforated astragalus, a long bone toggle (?), spindle whorl fashioned from a medium mammal femoral head, and the remains of a decorated bone box (?), has also provided further information into cremation practice in pre-history (Figure 5.12).

In addition to worked and unworked bone, there was also frequent evidence of previously unidentified pyre goods. These included fragments of pottery that had been heated, taking on an expanded and spongy appearance. The identification of burnt metal fragments was also common, frequently adhering to bone fragments. Other evidence (which was particularly prevalent in cremation deposits recovered from Ljubljana SAZU) for the presence of metal was observed as red and orange staining on the bone. Examples of this are shown in Figure 5.13.

Figure 5.11. Top: a fully calcined/cremated petrous bone from the cranium of horse or cattle, Kaptol; middle: tailbone of a medium-sized mammal, Kaptol; bottom: shattered animal tooth enamel, Kaptol T-6.

Figure 5.12. From the top: Outer view of a perforated medium-sized mammal femoral head, SAZU grave 145; inside view of the perforated femoral head, SAZU grave 145; worked bone fragment Kaptol T-XI; Perforated astragalus SAZU grave 109. All worked animal bone was cremated.

Figure 5.13. From the top: Iron fibula fragment with skull fragment adhering; Femoral head with metal staining; interior of femur long bone fragment with metal coating the trabeculae and cortical bone; Vertebral body with metal staining.

5.3 Cremated remains: age and sex

5.3.1 Sex

The results of sex assessment for cremated bone assemblages from Ljubljana SAZU, Kaptol and Kapiteljska njiva can be found in Table 5.6, Figure 5.14. For the most part, poor preservation and a lack of complete remains resulted in poor sex assessment data. In some cases, it was possible to observe either masculine or feminine traits (usually cranial), but most of the remains were reported as indeterminate.

%	Non-adult (unsexed)	Masculine traits	Feminine traits	Male	Female	Indeterminate
Ljubljana SAZU	15.0	6.0	3.0	1.0	0.0	75.0
Kaptol	30.0	0.0	0.0	0.0	0.0	70.0
Kapiteljska njiva	3.4	3.4	0.0	0.0	0.0	93.2

Table 5.6. Sex assessment of cremated remains (%) for the cemeteries of Kaptol (n=21), Ljubljana SAZU (n=167) and Kapiteljska njiva (n=60). Masculine and feminine trait categories indicate where some skeletal features were observed as potentially sexually dimorphic, but where sufficient evidence for sex assessment was not

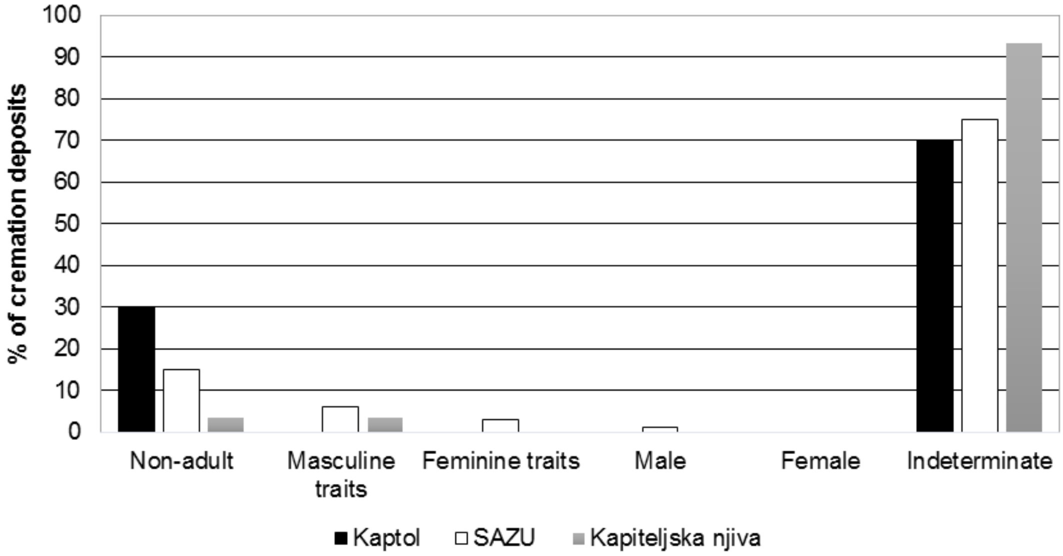


Figure 5.14 The results of sex assessment of cremated remains Kaptol (n=21), Ljubljana SAZU (n=167) and Kapiteljska njiva (n=60) (% of total cemetery). For example, 70% of cremated remains from Kaptol were of indeterminate sex. The Non-adult category has been included for comparison, but sex assessments were not attempted. Masculine and feminine trait categories indicate where some skeletal features were observed as potentially sexually dimorphic, but where sufficient evidence for sex assessment was not available.

5.3.2 Age estimation

The results of biological age estimation for cremated bone assemblages from Ljubljana SAZU, Kaptol and Kapiteljska njiva can be found in Table 5.7, Figure 5.15.

%	**Non-adult**	**Adult**	**Indeterminate**
Kaptol	30	45	25
Ljubljana SAZU	15	80	4
Kapiteljska njiva	3	70	27

Table 5.7. Age estimation of cremated remains expressed as a % of each cemetery for Kaptol (n=21), Ljubljana SAZU (n=167) and Kapiteljska njiva (n=60)

For most cases, it was possible to differentiate between adults and non-adults in cremation assemblages. This was done primarily through the identification of permanent teeth and bone fusion. Kaptol produced the highest percentage (30%) of non-adults across all the sites. This was followed by Ljubljana SAZU (15%) and then Kapiteljska njiva (3%).

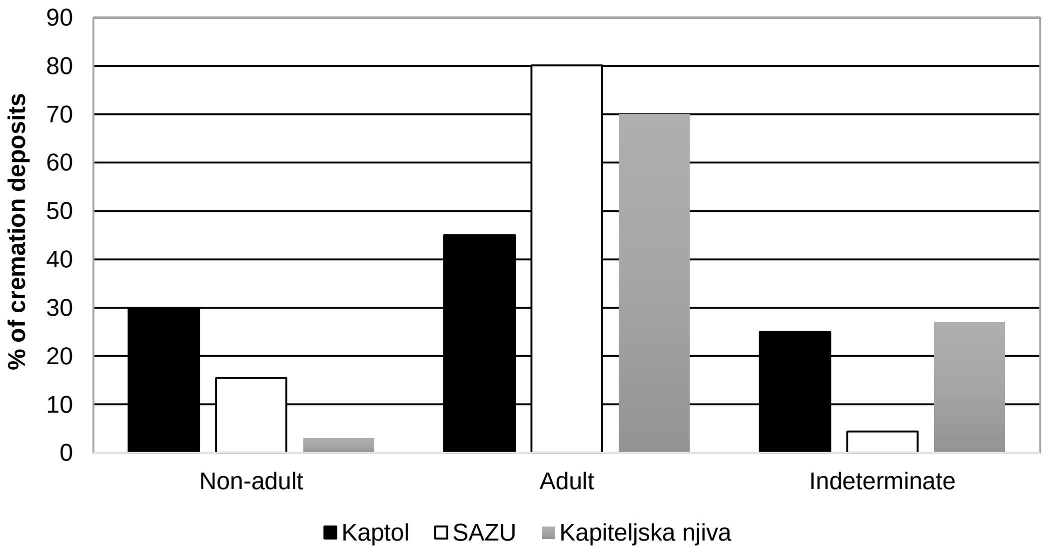


Figure 5.15. The results of age estimation analysis (% of each cemetery) for Kaptol (n=21), Ljubljana SAZU (n=167) and Kapiteljska njiva (n=60)

5.4 Cremated remains: multiple burials

From the cemetery site of Ljubljana SAZU, it was possible to identify 12% of graves as being multiple graves, with an MNI of two. This was most commonly a mix of adult and non-adult remains, though two adults were also identified in a single deposit by the observation of repeating bone elements. Additionally, there were occasions where the remains of a cremated individual were deposited with the unburnt remains of another individual, e.g. grave 246. Here, the unburnt parietal bones of a non-adult were found with the burnt remains of an adult (fused) proximal end of a femur (Figure 5.16).

Figure 5.16. Photograph: Ljubljana SAZU grave 264. The unburned parietal bones of a non-adult found in association with a burned proximal femur with fused head and burned occipital fragment. Source: author

No multiple graves were identified from the cemetery sites of Kapiteljska njiva or Kaptol, but this may be an artefact of high levels of incompleteness and a lower level of bone element identification. For this reason, it is difficult to suggest if the number of multiple graves from Ljubljana SAZU is exceptional, or whether this is just the result of taphonomy and/or sampling.

5.5 Cremated remains: bone colour

The following presents the results of the observation of colour across the assemblages of cremated remains from Kaptol, Ljubljana SAZU and Kapiteljska njiva. All the following plots present site scale percentages from identified bone elements. Individual grave observations of colour can be found in Appendix C, Disk 1.

For the purposes of this analysis, a spectrum of colours including white, grey, blue, purple, black and brown was chosen, as these were the most commonly identified during the analysis of cremated bone, though it is acknowledged that within these categories there was also a range of lighter/darker shades. This range of colours has, nonetheless, been found to be appropriate for the succinct demonstration of overall colour variation. These colours were recorded for different skeletal areas (cranial, axial, upper and lower limb) as a method of detecting potential temperature variation across the skeleton during the cremation process. For example, skeletal regions exhibiting light colours (white/grey) would have reached higher temperatures than areas with darker colours (black/brown) (Walker et al. 2008). From this, patterns of burning and the condition of the body post-cremation (presence of organic material or soft tissue) could be inferred (Alunni et al. 2014).

5.5.1 Kaptol

The percentage of cremation deposits for the site of Kaptol where different bone colours were observed to be present across different skeletal regions can be found in Table 5.8 and in Figure 5.17. This was calculated by dividing cremation deposits into the skeletal regions of the skull, axial skeleton, upper limb and lower limb. The total number of grave deposits where a colour was identified for each skeletal region (e.g. white skull fragments) was calculated. This total was then converted into a percentage by calculating the sum number of grave deposits where a colour was identified, by skeletal region, and dividing this by the number of graves in each cemetery. For example, 18 of 21 grave deposits from Kaptol had white skull fragments. When converted into a percentage, 86% of grave deposits from Kaptol had white skull fragments. This conversion to a percentage allows for the comparison of colour between skeletal regions at a cemetery level and between cemeteries.

As there is a high likelihood of multiple colours being identified simultaneously in any skeletal region, the percentages obtained from each region at the cemetery level may add up to more than 100%. For example, 86% of grave deposits from Kaptol had white skull fragments, but 33% of grave deposits also had grey skull fragments, which equals more than 100%.

% Present	White	Grey	Blue	Purple	Black	Brown	N/A
Skull	86	33	5	0	14	0	14
Axial	57	24	5	0	14	5	38
Upper limb	76	38	5	0	48	0	19
Lower limb	62	29	5	0	43	5	33

Table 5.8. Kaptol (n=21): the percentage of cremation deposits where a colour was observed across different skeletal regions. N/A refers to instances where this skeletal region was absent.

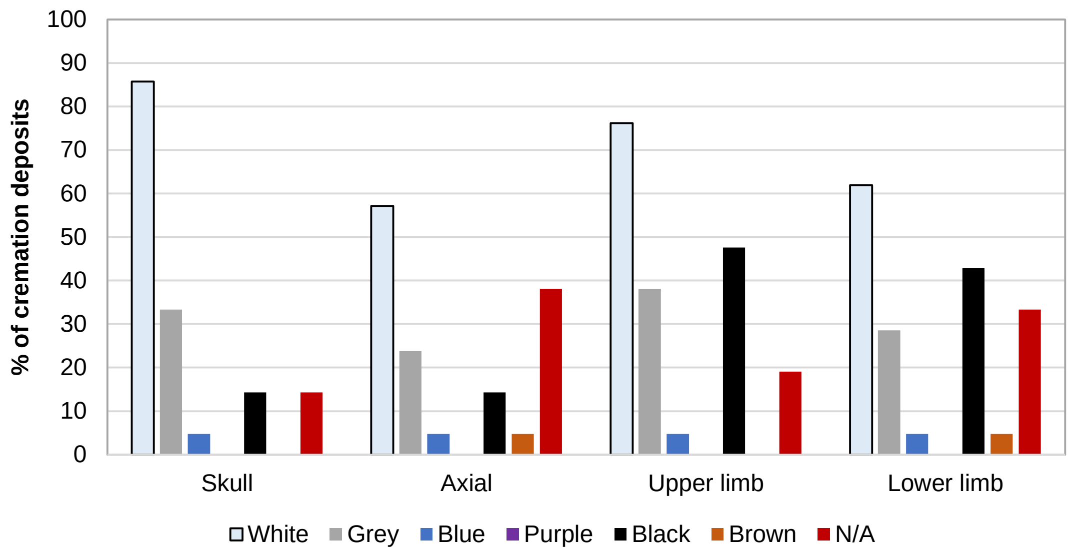


Figure 5.17. Kaptol (n=21): The number of cremation deposits expressed as a % of the whole cemetery, where a bone colour was identified, by skeletal region. N/A (red) represents the percentage of individuals where a skeletal region was absent. For example, 86% of cremation deposits from Kaptol had white skull fragments.

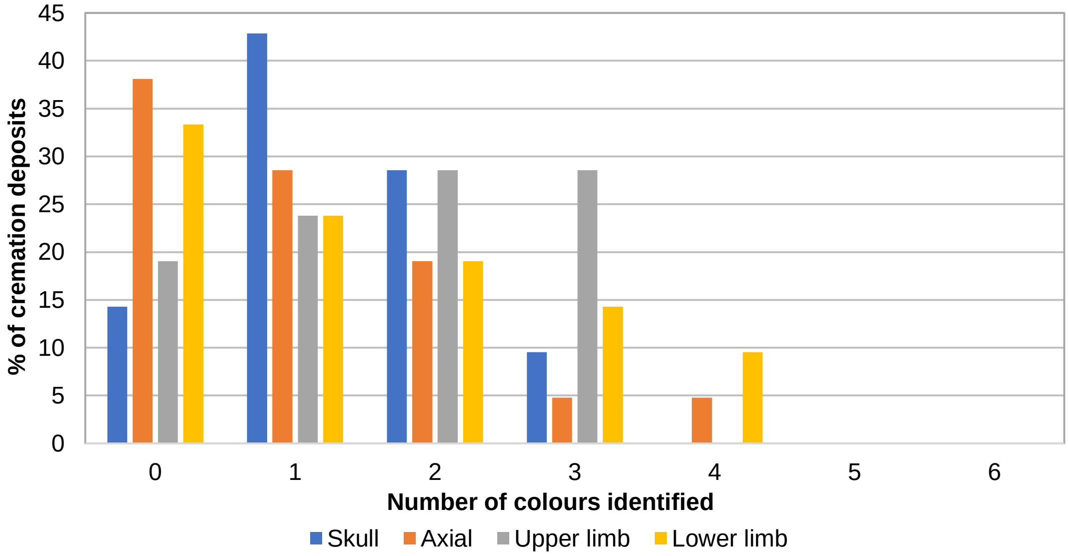
Across the cremated bone assemblage of Kaptol, white was observed to be the most common colour in all skeletal regions. The next most common colour, overall, was grey, though black was also very common in upper and lower limb bones. Where black was observed, this was regularly as a thin line within the core of thicker long bones (e.g. femur fragments) or lining the interior of the medullary cavity and within the trabecular bone. This pattern was most commonly seen in association with white and grey cortical bone. Combinations of black, blue and brown were most commonly found within the trabecular bone of larger bone fragments. It was also noted that this pattern of colouration was observable within the cremated animal bone, suggesting a similar treatment.

In addition to the presence/absence of particular colours, the number of colours observed within each skeletal region may provide further information about the funerary process at Kaptol. The percentage of cremation deposits with different numbers of colours observed across different skeletal regions can be found in Table 5.9 and in Figure 5.18. The category of zero colours is included to indicate where elements from a skeletal region were absent, and so colour variation is unknown. This was calculated by dividing each deposit into its different skeletal regions and then counting the number of colours observed (e.g. white and grey = 2). The sum of deposits per skeletal region with each number of colours was calculated and subsequently converted into a percentage to make the values comparable. For example, 9 of 21, or 43%, of grave deposits from Kaptol had only 1 observable colour on skull fragments.

No. colours in one skeletal region (%)	0 (unrecovered)	1	2	3	4	5	6
Skull	14	43	29	10	0	0	0
Axial	38	29	19	5	5	0	0
Upper limb	19	24	29	29	0	0	0
Lower limb	33	24	19	14	10	0	0

Table 5.9. Kaptol (n=21): the percentage of cremation deposits with different numbers of colours (0-6) identified in each skeletal region. N/A refers to instances where this skeletal region was absent

Across the assemblage, between one and three colours were most commonly observed in a skeletal region. As discussed in the previous section, this variation was most commonly a mix of white, grey and black, though there were also combinations of black, blue and brown in larger pieces of trabecular bone. This variation in colour may indicate that similar patterns of heat exposure were present across the skull, axial skeleton, upper limb and lower limb. In some instances, four different colours were noted in the lower limb and across the axial skeleton. This indicates an increased variation in heat exposure and is probably linked to the location of the bones within the body (Alunni et al. 2014). This increased variation was typically observed within femoral fragments and fragments of the pelvis - areas which would have had extra protection from heat due to a higher incidence of muscle and soft tissue coverage (Alunni et al. 2014).



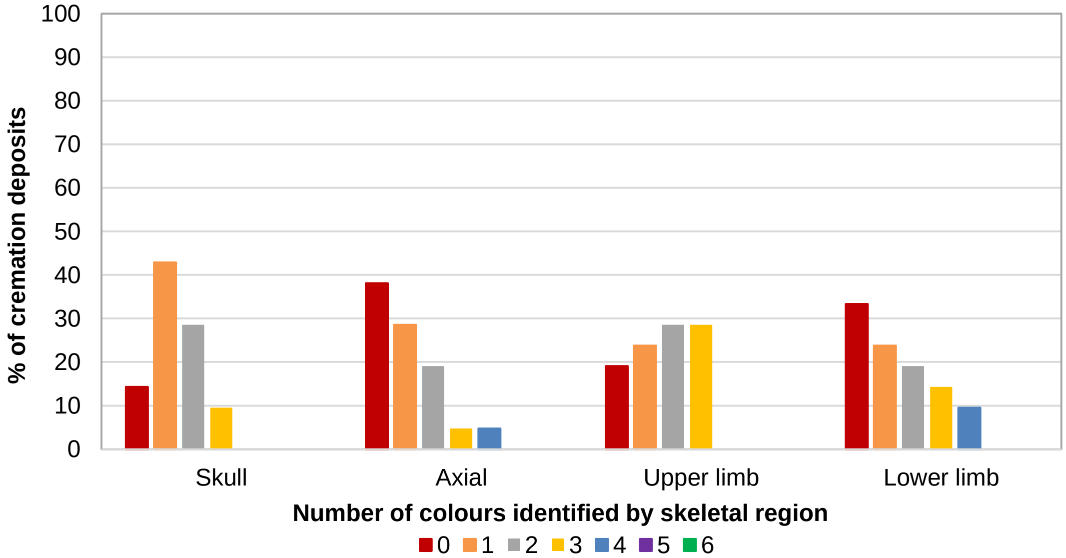


Figure 5.18. Kaptol (n=21): colour variation expressed as the % number cremation deposits, where different numbers of colours were identified across different skeletal regions. 0 represents absent skeletal regions. For example, 43% of cremation deposits from Kaptol had skull fragments where only 1 colour was identified.

White cortical bone would suggest that the bone reached a minimum temperature of around 650°C. The black and blue observed within the medullary cavity and trabecular bone would indicate that this temperature did not penetrate through some of the larger long bones (Walker et al. 2008). The identification of a high proportion of bones white throughout would suggest that many of the Kaptol bones reached temperatures of above 650°C and that the duration of burning was sufficient for all the organic component of the bone to be removed (Walker et al. 2008; Devlin and Herrmann 2015).

5.5.2 Kapiteljska njiva

The percentage of cremation deposits for the site of Kapiteljska njiva where different bone colours were observed to be present across different skeletal regions can is shown in Table 5.10 and in Figure 5.19.

% Present	White	Grey	Blue	Purple	Black	Brown	N/A
Skull	93	57	33	0	12	0	7
Axial	35	18	8	0	2	0	60
Upper limb	63	38	23	0	8	0	35
Lower limb	62	50	32	0	20	0	32

Table 5.10. Kapiteljska njiva (n=60): the percentage of cremation deposits where a colour was across different skeletal regions. N/A refers to instances where this skeletal region was absent.

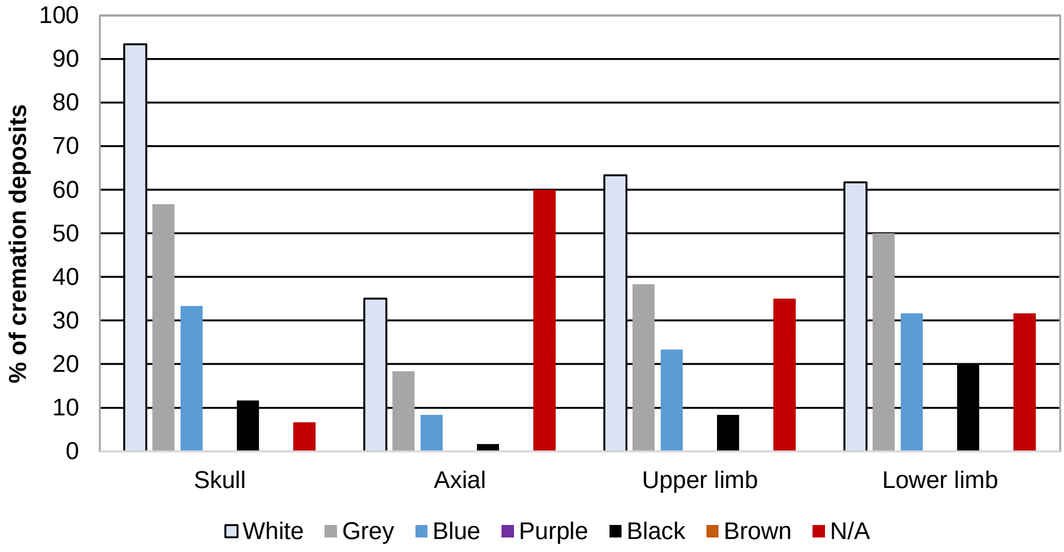


Figure 5.19. Kapiteljska njiva (n=60): the number of cremation deposits, expressed as a % of the whole cemetery, where a bone colour was identified, by skeletal region. N/A (red) represents the percentage of individuals where a skeletal region was absent. For example, 93% of cremation deposits from Kapiteljska njiva had white skull fragments.

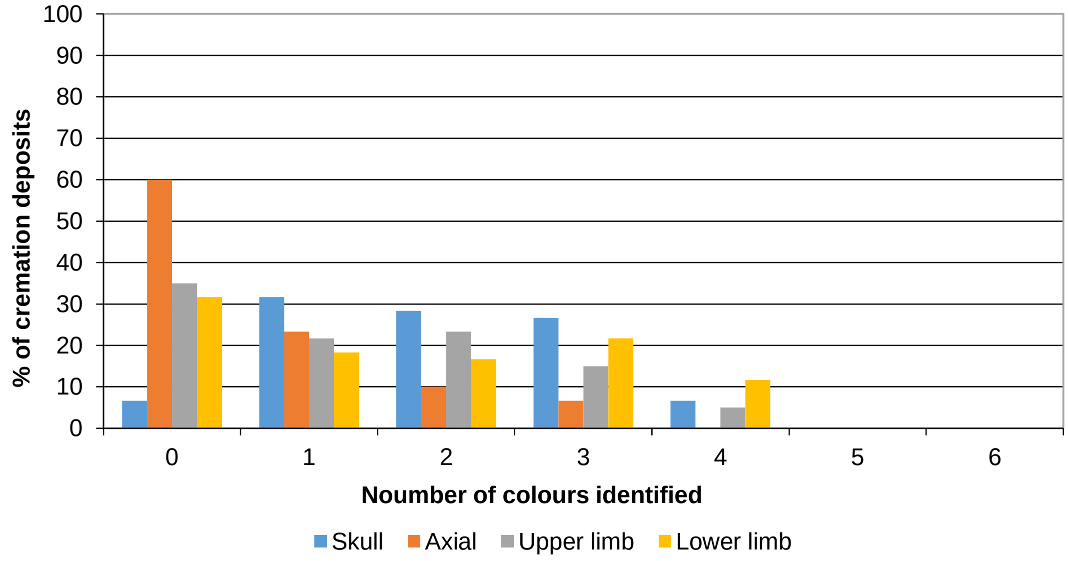
Across the cremated bone assemblage of Kapiteljska njiva, white was observed to be the most common colour across all skeletal regions. The next most common colour was grey, followed by blue and then black. For the most part, darker colours (e.g. blue and black) were observed lining the inside of the medullary cavity of larger long bones, e.g. femur, tibia and humerus fragments. This was frequently associated with a mix of white and grey external cortical surfaces. Where black was observed in the skull, this was commonly found on more dense fragments, such as the petrous bone, but also on parietal and occipital fragments. Blue and grey were frequently observed within the diploe of cranial fragments, while the outer table was also frequently white/grey.

The percentage of cremation deposits where different numbers of colours were observed across different skeletal regions for the site of Kapiteljska njiva is shown in Table 5.11 and in Figure 5.20.

No. colours in one skeletal region (%)	0	1	2	3	4	5	6
Skull	7	32	28	27	7	0	0
Axial	60	23	10	7	0	0	0
Upper limb	35	22	23	15	5	0	0
Lower limb	32	18	17	22	12	0	0

Table 5.11. Kapiteljska njiva (n=60): the percentage of cremation deposits with different numbers of colours (0-6) identified in each skeletal region. N/A refers to instances where this skeletal region was absent

Across the assemblage, between one and three colours were most commonly observed in a skeletal region, though a combination of four colours was reasonably frequent in the lower limb and occasionally noted elsewhere. As has been discussed in the previous section, this variation was most commonly a mix of white, grey, and blue, with instances of black in larger fragments of thicker long bones. This variation in colour indicates that similar, but not identical, patterns of heat exposure were present across the skull, upper limb and, to a lesser extent, lower limb. As shown in Figure 5.20, it is difficult to judge whether this was also the case in the axial skeleton. A similar variation in colour has been observed, but there was also a significantly higher incidence of this skeletal region being absent (Table 5.11). Ribs and vertebral fragments were found relatively frequently (usually white/grey), but fragments of the pelvis, for example, were rare. The axial skeleton may well have had an increased amount of colour variation due to its central location in the body and increased soft tissue coverage.



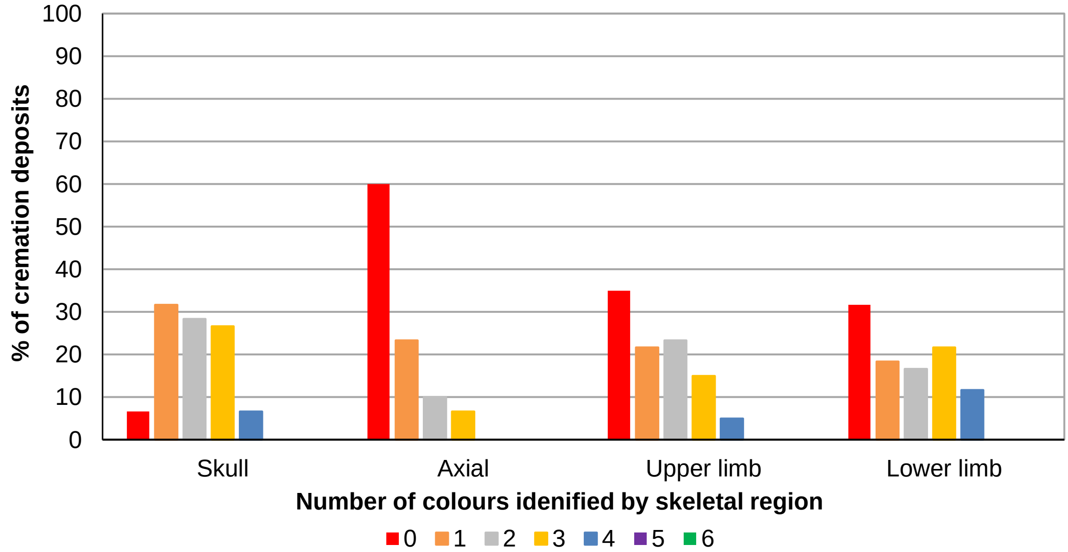


Figure 5.20 Kapiteljska njiva (n=60): colour variation expressed as the % number cremation deposits, where different numbers of colours were identified across different skeletal regions. 0 represents absent skeletal regions. For example, 32% of cremation deposits from Kapiteljska njiva had skull fragments with 1 colour identified

Bone colour observations from cremated remains from the cemetery site at Kapiteljska njiva suggest that the external surfaces of the majority of bone elements reached a temperature of at least 650°C, subsequently turning the cortical bone white (Walker et al. 2008; Devlin and Herrmann 2015). Darker colours of blue and sometimes black, seen to line the internal surfaces of bones and thicker skull fragments suggests that this high temperature did not always penetrate some of the larger long bones of the lower limb or some of the internal structures of the cranium. This is perhaps because the duration of the cremation process may not have been sufficient for the removal of the organic component of the bone, or the latter stages of heat-induced modifications, as described in Section 3.1.2 (Walker et al. 2008; Devlin and Herrmann 2015).

5.5.3 Ljubljana SAZU

The percentage of cremation deposits for the site of Ljubljana SAZU, where different colours were identified across different skeletal regions, can be found in Table 5.12 and in Figure 5.21.

% Present	**White**	**Grey**	**Blue**	**Purple**	**Black**	**Brown**	**N/A**
Skull	95	79	79	14	35	9	4
Axial	71	47	40	2	14	4	26
Upper limb	83	62	57	3	23	7	16
Lower limb	92	81	72	8	44	10	7

Table 5.12. Ljubljana SAZU (n=167): the percentage of cremation deposits where a colour was identified across different skeletal regions. N/A refers to instances where this skeletal region was absent

Across the cremated bone assemblage of Ljubljana SAZU, white was observed to be the most common colour across all skeletal areas. Grey and blue were also exceptionally common across all skeletal elements. These two colours were noted on both the inside and outside surfaces of long bones, as well as across the inner and outer tables of cranial fragments, and within the diploe. Overall, although white was present on almost all skeletal elements, darker colours of grey, blue, purple, and black were common in large areas, across this assemblage. Where black was observed, this was frequently found in large patches across bone fragments, commonly alongside purple and brown.

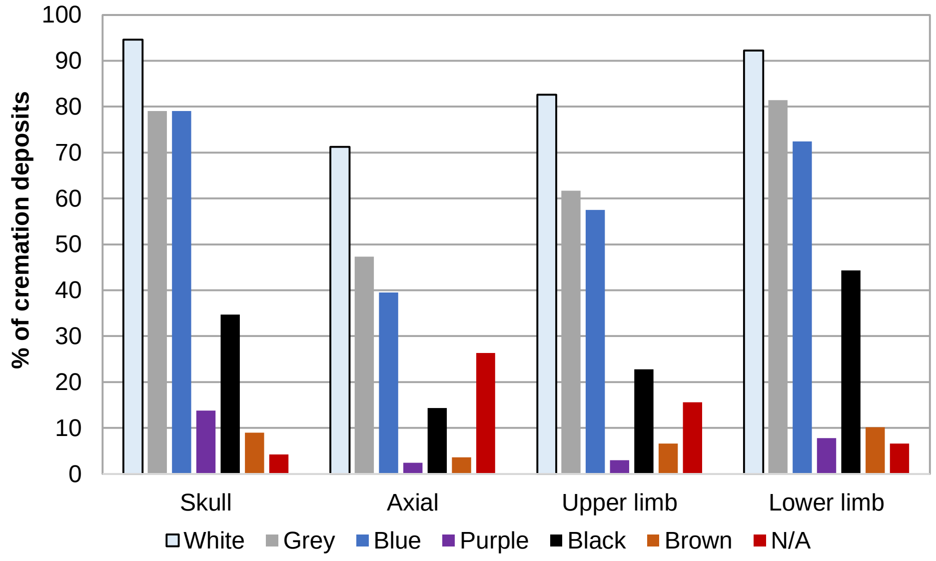


Figure 5.21 Ljubljana SAZU (n=167): the number of cremation deposits, expressed as a % of the whole cemetery, where a bone colour was identified, by skeletal region. N/A (red) represents the percentage of individuals where a skeletal region was absent. For example, 95% of cremation deposits from Ljubljana SAZU had white skull fragments.

The percentage of cremation deposits with different numbers of colours identified across different skeletal regions can be found in Table 5.13 and in Figures 5.22.

No. colours in one skeletal region (%)	*0*	*1*	*2*	*3*	*4*	*5*	*6*
Skull	4	8	11	38	28	8	2
Axial	26	20	17	23	11	1	0
Upper limb	16	16	17	32	14	5	1
Lower limb	7	7	13	33	29	9	2

Table 5.13. Ljubljana SAZU (n=167): the percentage of individuals with different numbers of colours (0-6) observed in each skeletal region. N/A refers to instances where this skeletal region was absent

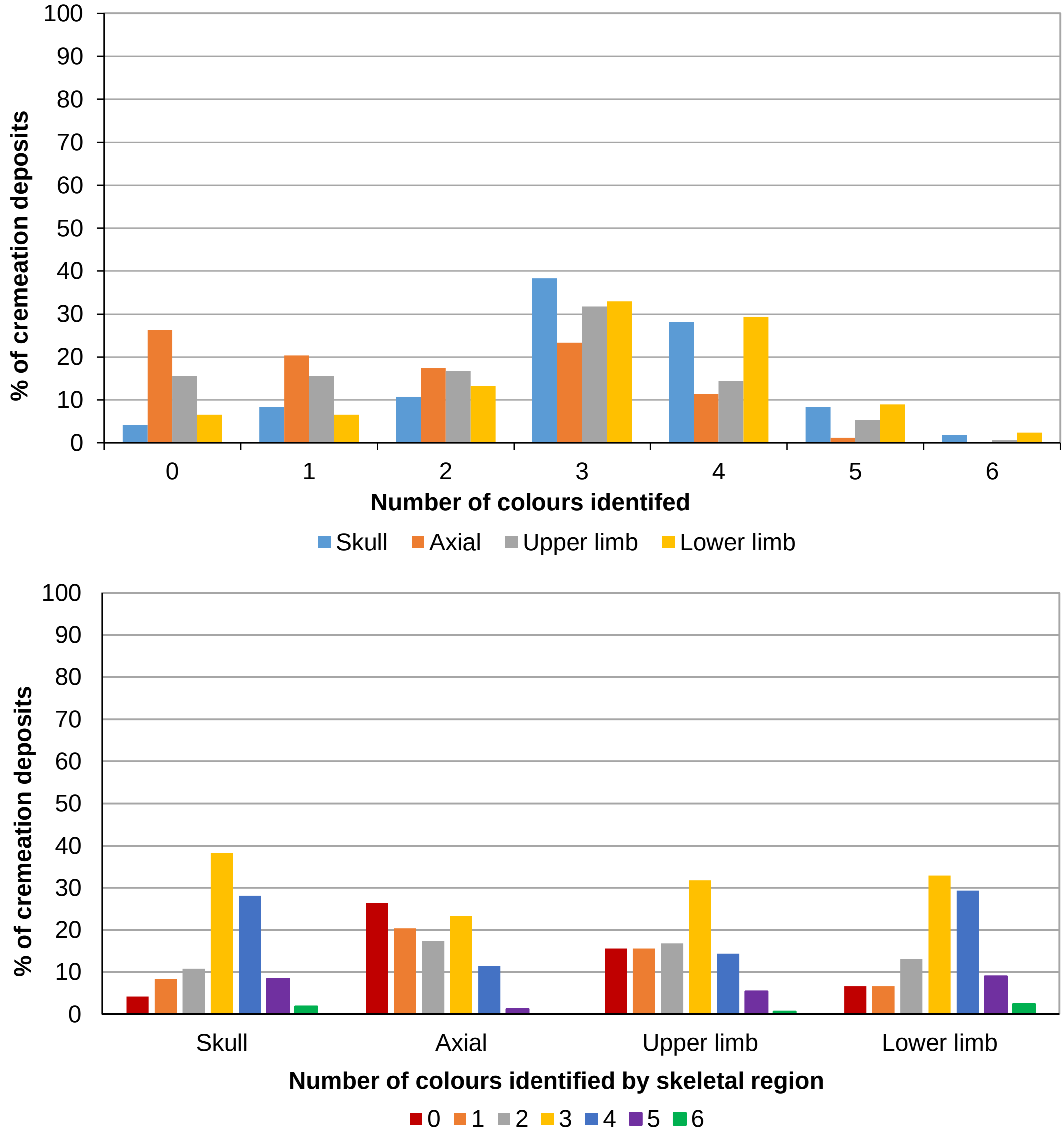


Figure 5.22. Ljubljana SAZU (n=167): colour variation expressed as the % number cremation deposits, where different numbers of colours were identified across different skeletal regions. 0 represents absent skeletal regions. For example, 8% of cremation deposits from Ljubljana SAZU had skull fragments with 1 colour identified

Across the assemblage, between one and four colours were most commonly observed in a skeletal region, although combinations of five and six colours were seen, primarily across larger long bones (e.g. tibia, femur and humerus). As has been discussed above, this variation was most commonly a mix of white, grey, blue and black, though there were also instances of black, purple and brown.

Individuals reflecting a higher variation in colour, for example, where bones are a mix of four to six colours, were more likely to have an increased frequency of darker colours, specifically blue, purple and black. This suggests that increased colour variation could be the result of lower temperatures or a shorter duration of time exposed to heat (Walker et al. 2008; Devlin and Herrmann 2015). Large areas of black, brown and blue on many bone elements, including long bones and skull fragments, indicates that bone did not reach temperatures higher than 300-500°C (Walker et al. 2008; Devlin and Herrmann 2015). In deposits where white bone is also prevalent, this variation could be related to the positioning of the corpse on the pyre, with, for example, the skull in a peripheral and subsequently cooler location. Darker colours found across long bones, such as those found in the lower limb, could be related to increased soft tissue coverage. Temperatures lower than 650°C are unlikely to adequately burn a body or lead to fully calcined bone, as the body fat will not have ignited (~800°C) to facilitate higher temperatures and the destruction of muscle and other soft tissues (Walker et al. 2008; Devlin and Herrmann 2015). Examples of these colour variations can be observed in Figures 23 to 25.

Figure 5.23. Cranial fragments from the cemetery site of Ljubljana SAZU. Fragments display a mix of brown, black, purple, blue, grey and white.

Figure 5.24. Proximal femur fragment from Ljubljana SAZU. A variation in colour is observable, with black and brown dominant around the neck, probably connected with its location within the body and increased soft tissue coverage.

Figure 5.25 Femur fragments from Ljubljana SAZU. A variation through white, grey and blue was noted on the external, cortical surface of the bone. The core and inner surfaces of the bone ranged through white, grey, black and blue. This variation suggests the bone reached up to a temperature of c.650, but this heat did not penetrate through the thickness of the bone. This was observed throughout the Ljubljana SAZU assemblage.

5.5.4 Bone colour: comparison of sites

<u>Percentages of bone colours</u>

Comparisons among the three sites where colours were identified across different skeletal regions can be found in Table 5.14 and in Figure 5.26.

% Present		White	Grey	Blue	Purple	Black	Brown	N/A
Ljubljana SAZU	**Skull**	95	79	79	14	35	9	4
	Axial	71	47	40	2	14	4	26
	Upper limb	83	62	57	3	23	7	16
	Lower limb	92	81	72	8	44	10	7
Kapiteljska njiva	**Skull**	93	57	33	0	12	0	7
	Axial	35	18	8	0	2	0	60
	Upper limb	63	38	23	0	8	0	35
	Lower limb	62	50	32	0	20	0	32
Kaptol	**Skull**	86	33	5	0	14	0	14
	Axial	57	24	5	0	14	5	38
	Upper limb	76	38	5	0	48	0	19
	Lower limb	62	29	5	0	43	5	33

Table 5.14. Site comparison: the percentage of individuals where a colour was identified across different skeletal regions. N/A refers to instances where this skeletal region was absent. Kaptol (n=21), Ljubljana SAZU (n=167) and Kapiteljska njiva (n=60)

White, grey and blue were observed to be the most frequent colours present in cremated bone assemblages from Kaptol, Kapiteljska njiva and Ljubljana SAZU. White and grey were the most common overall colours in remains from Kaptol, though black was found to be very frequent in small amounts in the larger long bones of the upper and lower limbs. Brown, purple and black were most frequently reported from Ljubljana SAZU. Brown and purple were missing from Kapiteljska njiva, and purple was also absent from the Kaptol assemblage, while brown was rare. Additionally, while darker colours were seen within the core and medullary cavity of long bones (or areas more likely to be protected by thicker layers of soft tissues, such as the pelvis and proximal femur) of Kaptol and Kapiteljska njiva, large areas from across the skeleton were more likely to be blue, purple and black throughout the bone in the Ljubljana SAZU assemblage. The differentiation in colour patterning observed throughout these assemblages of cremated remains may be reflecting variability in the cremation practices and processes carried out at these cemeteries (McKinley 2008b: 186-187).

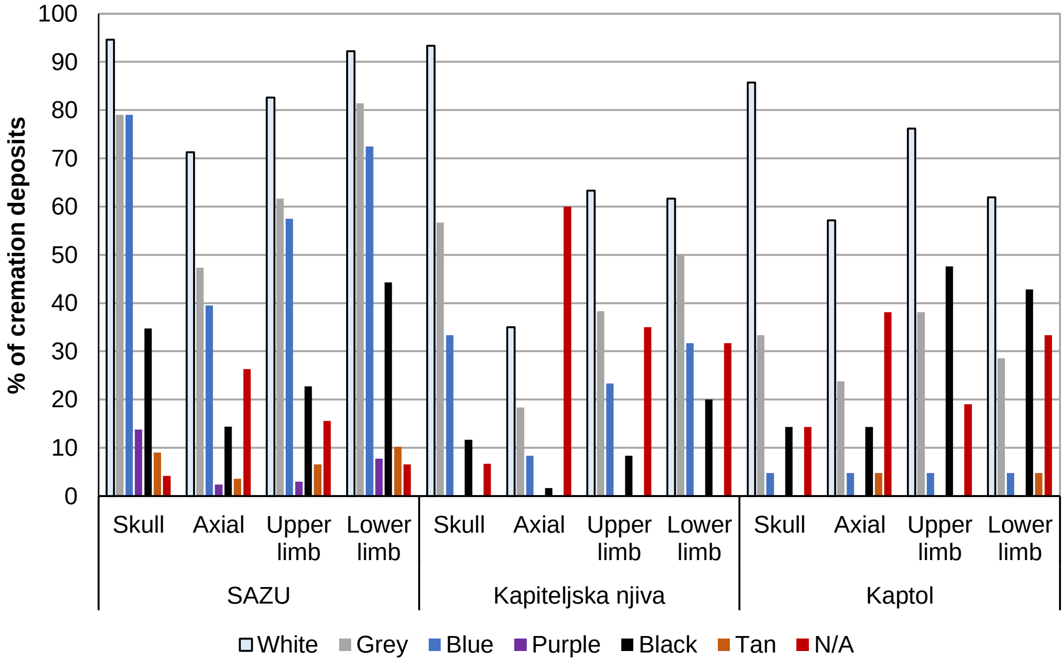


Figure 5.26 Site comparison: the number of individuals, expressed as a % of each cemetery, where a bone colour was identified, by skeletal region, by the site. Red represents the percentage of individuals where a skeletal region was absent. Kaptol (n=21), Ljubljana SAZU (n=167) and Kapiteljska njiva (n=60)

Percentages of colour variation

The percentage of individuals with different numbers of colours observed across different skeletal regions can be found in Table 5.15 and in Figure 5.27. All three sites had a variation of between one and three colours across all skeletal regions. For Kaptol and Kapiteljska njiva, this variation frequently ranged from white to grey and, to a lesser extent, to blue. This range was also observed in the Ljubljana SAZU assemblage; however, there was also an increased likelihood of variation between white and brown. Additionally, from Ljubljana SAZU, where three different colours were identified, it was also more likely that these comprised darker colours of grey, blue, purple, or black, while two-colour ranges were more likely to include black and brown.

No. colours /skeletal region (%)		0	1	2	3	4	5	6
Ljubljana SAZU	**Skull**	4	8	11	38	28	8	2
	Axial	26	20	17	23	11	1	0
	Upper limb	16	16	17	32	14	5	1
	Lower limb	7	7	13	33	29	9	2
Kapiteljska njiva	**Skull**	7	32	28	27	7	0	0
	Axial	60	23	10	7	0	0	0
	Upper limb	35	22	23	15	5	0	0
	Lower limb	32	18	17	22	12	0	0
Kaptol	**Skull**	14	43	29	10	0	0	0
	Axial	38	29	19	5	5	0	0
	Upper limb	19	24	29	29	0	0	0
	Lower limb	33	24	19	14	10	0	0

Table 5.15. Site comparison: the percentage of individuals with different numbers of colours (0-6) identified in each skeletal region. N/A refers to instances where this skeletal region was absent. Kaptol (n=21), Ljubljana SAZU (n=167) and Kapiteljska njiva (n=60)

The combination of the presence of darker colours and an increased variation in colour across skeletal areas has suggested that individuals from Ljubljana SAZU may have been less ‘successfully’ cremated than individuals from Kaptol or Kapiteljska njiva. This interpretation should, however, be treated with caution. As demonstrated by Figure 5.10, Ljubljana SAZU also had the highest representation of each skeletal region compared to the other two sites. More variation in colour may have existed in the remains from Kaptol and Kapiteljska njiva but was not observable due to many skeletal elements being missing (see Section 5.2).

Although the bone assemblages from Kaptol and Kapiteljska njiva were, for the most part, identified as being at the lighter end of the colour range (e.g. white and grey), the ranges of between three and four colours across skeletal regions, in addition to the identification of blue and black, indicate that the cremation process was not wholly successful in terms of complete removal of the organic component and calcification of the bone. The consistently higher levels of colour variation from Ljubljana SAZU cremation deposits, in addition to the more frequently observed darker colours, may indicate that a different pyre technology was being utilised, or a difference in approach to the cremation rite as a method of funerary treatment.

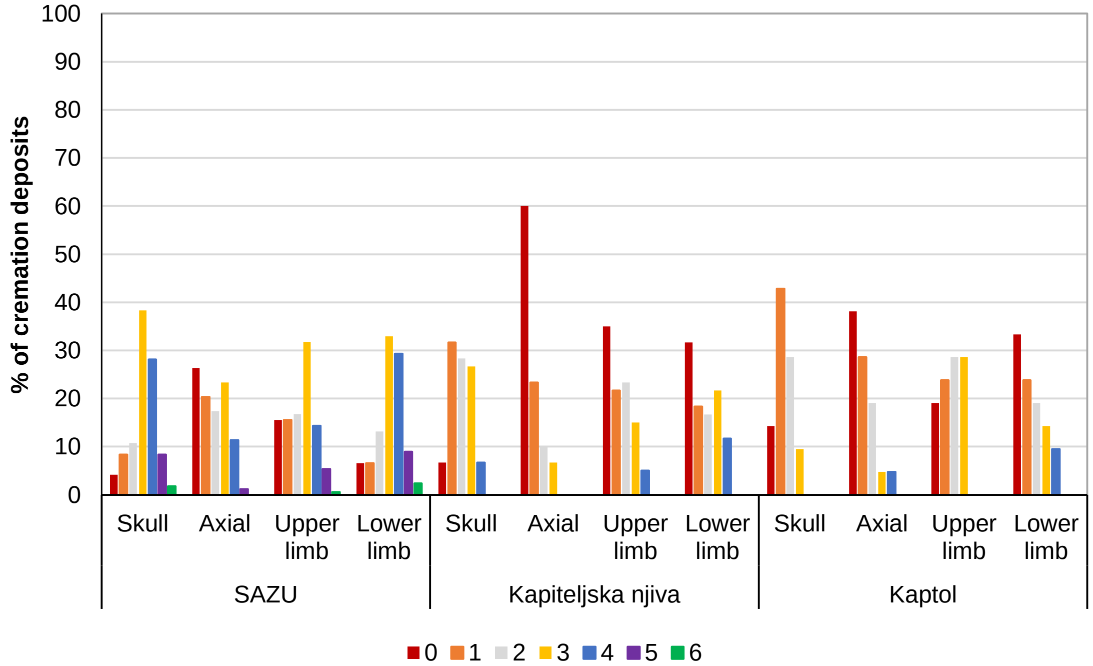


Figure 5.27. Site comparison: colour variation, expressed as the % number of individuals, where different numbers of colours were identified across different skeletal regions, by site. 0 represents the percentage of individuals where a skeletal region was missing. Kaptol (n=21), Ljubljana SAZU (n=167) and Kapiteljska njiva (n=60)

Although colour presence/absence and variation are subjective and not reliably quantifiable, the observation of these colour patterns has provided an interesting line of enquiry for future analyses. The differences seen in the colouration of cremated bone from Ljubljana SAZU in relation to other cemeteries from the same period (e.g. Kapiteljska njiva) have indicated a potential dissimilarity in the treatment of the dead and cremation processes. More objective methods, including FTIR, applied to these cremated remains would provide more quantifiable data, which could then be assessed for statistically significant differences (Walker et al. 2008; Thompson et al. 2009; Ellingham et al.).

5.6 Overview of the analysis of cremated remains

- High levels of taphonomic damage observed across all the cemeteries included in this analysis (low bone weights and high fragmentation) made the analysis of cremated remains difficult, resulting in low percentages of identified bone.
- For the most part, sex assessment was not possible because of absent diagnostic cranial and pelvic features.
- Broad distinctions between adult and non-adult were commonly possible, with Kaptol giving the highest frequency of non-adults (30% of analysed cremations)
- The majority of cremation deposits weighed <500g, with the most frequent total weight range being 11-100g
- Even when taking taphonomy into account, the low total bone weight indicates partial selection and collection of cremated remains for deposition.
- Evidence of multiple burials was common, particularly from Ljubljana SAZU (11% of analysed cremations).
- Animal bone was very common throughout the analysis of cremated remains, particularly from Kaptol. Species included horse, cattle, sheep/goat, dog and goose, the majority of which were fully cremated. The presence of long bones, tail bones, teeth and vertebrae (particularly from Kaptol) probably indicates the cremation of whole animals.
- There was strong evidence for the presence of Pyre goods, including pottery and metal objects, supporting the argument that the deceased was laid out upon the pyre dressed and with funerary offerings.
- The most commonly observed bone element from all of the cemeteries was the skull, though this may have been influenced by the ease of its identification. Larger long bones, including the femur and tibia, were well represented, while the axial skeleton was the least well represented.
- The most common bone colour observed across the cremated bone assemblages was white. Bone colour variation within the Kaptol and Kapiteljska njive assemblages was minimal, with some blue and black

lining medullary cavities. This suggests that most of the skeleton reached temperatures of at least 650°C and that the cremation lasted long enough for the removal of soft tissues. Ljubljana SAZU exhibited different colour patterning, commonly exhibiting darker colours of blue, black and purple throughout the different skeletal regions. This indicates that those cremated and deposited at Ljubljana SAZU were less successfully cremated in terms of removal of soft tissues and calcification of the bone.

Chapter 6 Results of carbon and nitrogen stable isotope analysis

The following chapter presents and discusses the results of carbon and nitrogen stable isotope analysis, including an animal baseline, the analysis of bulk collagen apex dentine, rib, and long bone samples, as well as incremental dentine analysis of both deciduous and permanent dentine. Finally, the results of the enamel carbonate analysis are presented in conjunction with $\delta^{13}C_{coll}$ values to investigate variations in the whole diet. The full data following carbon and nitrogen stable isotope analysis can be found in Appendix E, Disk 1.

All bone samples included produced >1% collagen yield. All samples presented had C: N ratios between 2.9 and 3.5, indicative of well-preserved collagen (Van-Klinken 1999).

6.1 Animal baseline

As already discussed in Section 2.3, a local and broadly contemporaneous carbon and nitrogen isotope animal baseline was constructed to identify the isotopic composition of animal products humans may have been consuming (Fraser et al. 2011). Isotope ratios representing a regional scale baseline, including domesticated animals (cattle, pig, sheep/goat) and wild animals (deer and freshwater fish) can be found in Table 6.1 and Figure 6.1. Human data is plotted by site against this baseline in Figures 6.2, 6.3 and 6.4.

For the most part, the expected trophic shifts between herbivores and omnivores are observable, notably between cattle and pigs, the latter of which was probably fed on a diet like that of humans (Hedges and Reynard 2007).

Species	$\delta^{13}C$‰	$\delta^{15}N$‰	C:N
Cattle			
Zagorje ob Savi	-19.7	6.0	3.2
Zagorje ob Savi	-19.0	4.8	3.2
Zagorje ob Savi	-18.5	6.7	3.3
Zagorje ob Savi	-19.2	6.3	3.2
CRT	-19.8	4.5	3.2
Metlika	-20.8	4.1	3.2
Gorenja vas	-19.1	6.3	3.2
Gorenja vas	-18.3	6.5	3.2
Gorenja vas	-17.9	6.3	3.2
Ljubljana Congress Square	-20.5	4.2	3.3
Novo mesto	-21.2	4.2	3.2
Sheep			
CRT	-21.4	4.6	3.2
Tribuna	-19.7	5.8	3.5
Gorenja vas	-19.9	5.6	3.2
Ljubljana Congress Square	-16.6	9.2	3.3
Ljubljana Congress Square	-18.4	8.5	3.6
Pig			
Zagorje ob Savi	-19.3	4.8	3.3
Zagorje ob Savi	-21.0	6.3	3.2
CRT	-19.8	4.5	3.2
CRT	-15.6	8.8	3.2
Crnomelj-zupnisce	-17.2	6.0	3.2
Metlika	-19.8	6.2	3.4
Metlika	-13.9	8.1	3.2
Gorenja vas	-13.9	8.6	3.3
Gorenja vas	-14.4	8.8	3.2
Ljubljana Congress Square	-18.1	0.7	3.2
Ljubljana Congress Square	-18.2	0.3	3.3
Novo mesto	-15.0	6.7	3.2
Deer			
Zagorje ob Savi	-23.1	3.3	3.3
Ljubljana Congress Square	-22.1	4.0	3.2
Ljubljana Congress Square	-22.0	2.4	3.3
Riverine Fish			
Ljubljana Sazu	-27.8	11.1	3.4

Table 6.1. $\delta^{13}C$ and $\delta^{15}N$ values of cattle, sheep/goat, pig, deer and riverine fish making up the ENTRANS animal baseline

6.1.1 Domesticated animals

Cattle

The cattle appear to fall into two groups. This may indicate a difference in animal husbandry practices between sites around Ljubljana, Novo mesto and Metlika (Group 1) in comparison to settlements linked to the cemeteries at Dolge njive (Gorenja vas) and Zagorje ob Savi (Group 2). The carbon isotopic ratios of cattle from Group 1 mainly range between ~-21‰ and ~-19.8‰, suggestive of a primarily C3 based diet. This indicates that millet was not used routinely as a source of cattle fodder (Tafuri et al. 2009). The slightly higher $\delta^{13}C$ values from Group 2 of ~-19‰ to ~-17‰ could be linked to the consumption of native C4 grasses, weeds and sedges (Čarni and Mucina 1998; Pyankov et al. 2010). These have been identified across central Europe, usually dominated by C4 annuals rather than perennials (Čarni and Mucina 1998; Pyankov et al. 2010). Alternatively, these isotope ratios could be a result of a minimal C4 input from seasonal foddering, or from grazing cultivated fields to improve soil fertility by producing manure (Madgwick et al. 2012). Either of these latter theories is loosely supported by the $\delta^{15}N$ values, where the first group of cattle have $\delta^{15}N$ values of between ~4‰ and ~5‰, while the $\delta^{15}N$ values of the second group range between ~6‰ to 6.7‰. As animals with higher $\delta^{15}N$ values tend to also have higher $\delta^{13}C$ values, this provides a tenuous link between C4 based protein and food from nitrogen enriched land as a side effect of cultivation (Bogaard et al. 2007; Fraser et al. 2011; Madgwick et al. 2012; Bogaard et al. 2013).

Sheep/goat

Wide ranges of $\delta^{13}C$ and $\delta^{15}N$ values were produced by the sheep/goat category. $\delta^{13}C$ values range between -21.4‰ and -16.6‰ and $\delta^{15}N$ values range between 4.6‰ and 9.2‰. These wider ranges in isotope ratios could be due to differences in husbandry practices between sites, whereby sheep from Ljubljana Congress Square were foddered on millet (Pechenkina et al. 2005; Tafuri et al. 2009). In a similar manner to Group 2 from the cattle remains, the lowest $\delta^{13}C$ values are associated with the lowest $\delta^{15}N$ values and vice versa. This suggests that there may be a link between C4 diet and food cultivated on nitrogen enriched land. Caprines may have been left to graze arable land following a harvest. This practice is known as a method of field clearance, for providing manure, and maintaining soil structure (Bogaard 2004; Bogaard 2005) (Halstead 2006: 44-46). If sheep were left to graze land cultivated for millet production, this would feasibly result in both the high $\delta^{13}C$ and $\delta^{15}N$ values (Bogaard 2005; Fraser et al. 2011; Madgwick et al. 2012; Bogaard et al. 2013).

Alternatively, due to the problems separating sheep and goat remains, the higher $\delta^{13}C$ values could be due to goats scavenging or being directly fed the remains of human plant foods or crop waste. However, as goats are not omnivores, the relatively higher $\delta^{15}N$ values of 9.2‰ are less easily supported by this hypothesis. These high $\delta^{13}C$ values also suggest that the influence of native C4 plants is less likely. To produce $\delta^{13}C$ values of -16‰, a considerable quantity of these grasses and sedges would have been required.

Pigs

When the Ljubljana samples are excluded (these are discussed below), the $\delta^{13}C$ and $\delta^{15}N$ values from pig bones range from -21‰ to -13.9‰, and from 4.8‰ to 8.8‰ respectively. For the most part, $\delta^{15}N$ values are higher relative to the other domesticates (cattle and sheep/goat), which is probably reflecting a more omnivorous diet, commonly associated with pigs (Hamilton et al. 2009). Furthermore, when the pigs are compared to human collagen samples, data points from the two species commonly fall in a similar position, suggesting that in some cases pigs were likely fed on, or scavenged, the scraps from the human diet or faeces. This interpretation has been previously made in other isotopic studies of Iron Age pigs (Hamilton et al. 2009; Hamilton and Thomas 2012; Madgwick et al. 2012). Higher $\delta^{15}N$ values may also be linked to foraging on cultivated land (Hamilton and Thomas 2012).

The wide range of both carbon and nitrogen isotopic ratios indicate a variety of approaches to pig husbandry (Hamilton and Thomas 2012). This observation is more prominent in the $\delta^{13}C$ values, where animals collected from CRT, Novo mesto and Gorenja vas exhibit a clear C4 signal, while samples from Zagorje ob Savi do not provide evidence of significant C4 consumption. Pigs from Metlika give evidence of both C3 and C4 based diet.

The C4 signal seen from these animals does not necessarily mean that millet was used specifically as animal fodder, as these pigs were probably fed a diet from a range of sources, including human food/crop waste and/or faeces. In the wild, pigs exploit a very adaptable subsistence strategy, being able to consume an abundance of resources including plants, roots, tubers, fungi, insects, excrement, carrion meat, bone, and more (Hamilton et al. 2009; Hamilton and Thomas 2012; Madgwick et al. 2012). This allows domesticated pigs to be kept with minimal effort and expense to the community, feeding them on whatever is available at the time. They can be penned or allowed to roam in order to supplement their own diet (Hamilton et al. 2009; Hamilton and Thomas 2012). This lack of specialisation likely accounts for the isotopic variation seen in this dataset.

The case of the two pigs from Ljubljana Congress Square is particularly interesting. These pigs have $\delta^{13}C$ values of -18.1‰ and -18.2‰ and $\delta^{15}N$ values of 0.7‰ and 0.3‰ respectively. These two animals were young juveniles and samples were taken from two scapulae of different sizes and the same side. The relatively high $\delta^{13}C$ values compared to other C3 consuming domesticates could suggest a diet of, for example, fungi (Hamilton et al. 2009; Hamilton and Thomas 2012). However, it has been argued that fungi, although variable, should have $\delta^{15}N$ values slightly higher than that of the local plant life (Hamilton et al. 2009; Millard et al. 2013; Szpak 2014). If these pigs were consuming a high quantity of fungi, which has a high protein content, this would result in pig $\delta^{15}N$ values being slightly higher than cattle or sheep consuming local, naturally occurring plants (Hamilton et al. 2009; Millard et al. 2013). Consequently, this hypothesis does not account for the exceptionally low $\delta^{15}N$ values obtained from these pig remains. Unfortunately, no other skeletal elements were available for these individuals and no adult pig remains from this site were of a suitable preservation for collagen extraction.

6.1.2 Wild animals

Deer

There appears to be a small shift in the carbon and nitrogen isotope ratios between wild (i.e. deer) and domesticated animals. This is likely due to the higher levels of controlled feeding in domesticated animal populations, including potential penning, which can raise $\delta^{15}N$ values if animals are consuming vegetation grown in soil ^{15}N enriched by their faeces, and foddering, where fodder may have similarly been grown on land ^{15}N enriched with manure (Bogaard et al. 2007; Fraser et al. 2011). Additionally, if this fodder included C4 plants (grain or crop waste), $\delta^{13}C$ values would also be increased relative to non-foddered animals (Tieszen 1991; Tafuri et al. 2009).

Furthermore, if the deer were living under heavily forested conditions, the $\delta^{13}C$ values produced from their bone collagen could be reflecting the 'canopy effect', where plants become depleted in ^{13}C because of either reduced light intensity or recycled CO_2 (van der Merwe and Medina 1991; Noe-Nygaard et al. 2005; Bonafini et al. 2013). This depletion is then transmitted up the food chain. If this were the case, the consumption of vegetation under forest conditions could mask the consumption of native C4 species.

Freshwater fish

Only one freshwater fish bone was included as part of the animal baseline. Excavation practices in the area do not routinely include sieving for small faunal remains and consequently, fish remains are almost never archived (M. Mason pers. comm. 2017). The unburned fish vertebrae, probably of a riverine trout (identification by Clare Rainsford), was retrieved from a set of cremated remains excavated from Ljubljana SAZU (Grave 109). The fish was probably sourced from the nearby Ljubljanica river. The bone produced a $\delta^{13}C$ value of -21.8‰ and a $\delta^{15}N$ value of 11.1‰. More samples are required to obtain an adequate range of $\delta^{13}C$ and $\delta^{15}N$ values to address the potential of riverine food sources, as freshwater based isotopic ratios are known to vary greatly (Katzenberg and Weber 1999).

6.1.3 Overview of animal baseline

Although this baseline has been constructed from a small number of remains, consisting of few species, these isotope results have offered some interesting glimpses into to husbandry practices and livestock management in later prehistoric Slovenia:

- There is a distinction in the $\delta^{13}C$ and $\delta^{15}N$ values between domesticated and wild animals
- Higher $\delta^{15}N$ values from domesticated animals relative to wild animals could be evidence for the grazing of cultivated land and the practice of manuring.
- Higher $\delta^{13}C$ values from domesticated animals, relative to wild animals, are evidence for the variable consumption of C4 plants either as fodder, crop waste or as field management/clearance. However, the possibility of native C4 species also requires consideration.
- Pig management may have been geographically diverse.
- Pigs were likely fed scraps/ waste of humans.
- $\delta^{13}C$ values from cattle, pigs, humans and sheep/goats have evidenced the prolific consumption of, and interaction with, C4 plants (probably millet).
- Isotopic ratios indicate that millet was not cultivated as a means of maintaining livestock but may have been part of a system of agricultural co-management of crops and domesticated animals.
- More samples representing more individuals and species are required to further investigate agricultural and husbandry practices.

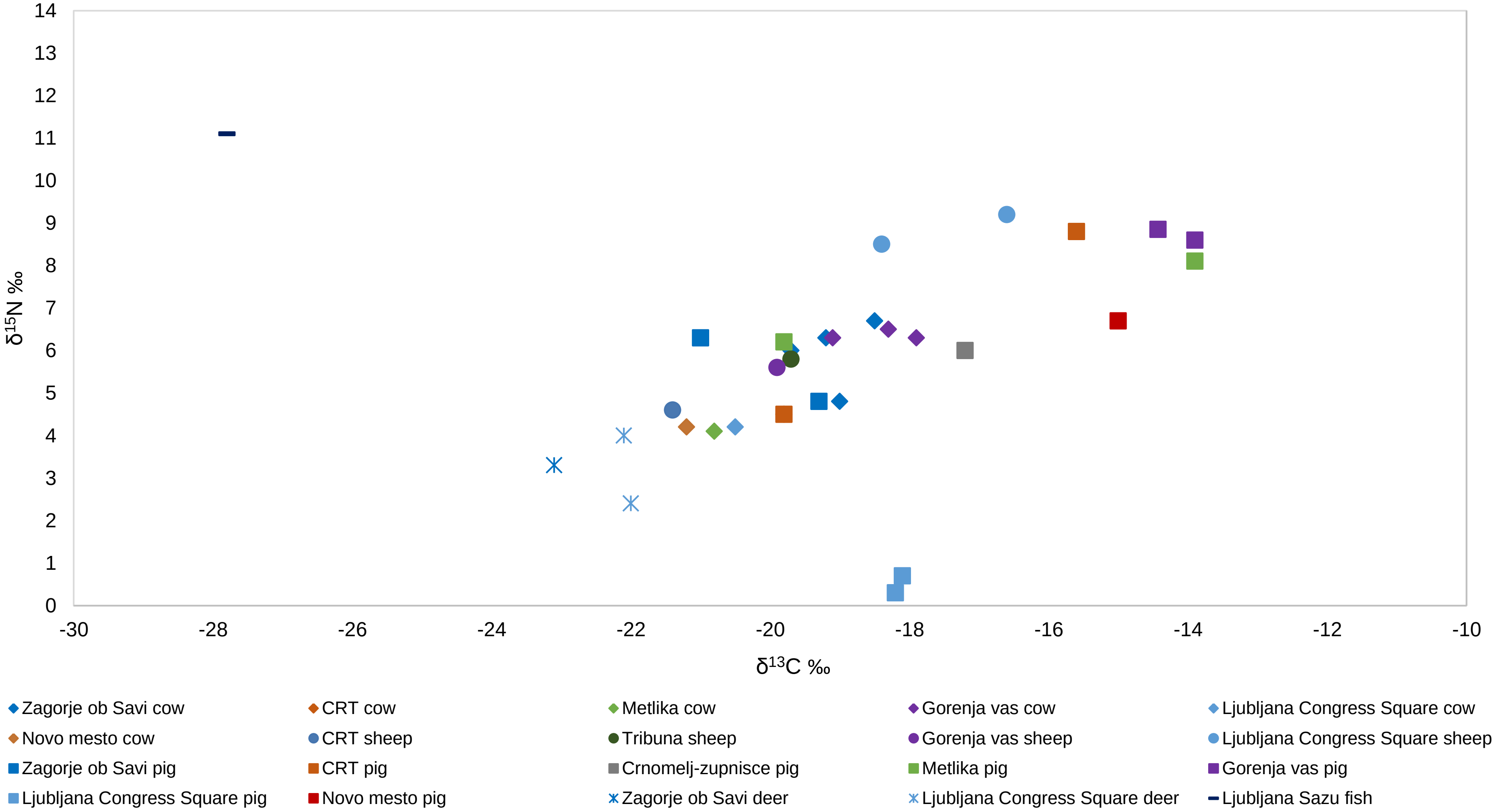


Figure 6.1. A plot of $\delta^{13}C$ and $\delta^{15}N$ values from the bone collagen of animals, which are local and broadly contemporary to the human remains. This data forms an animal baseline, with different species indicated and separated by the site the of origin.

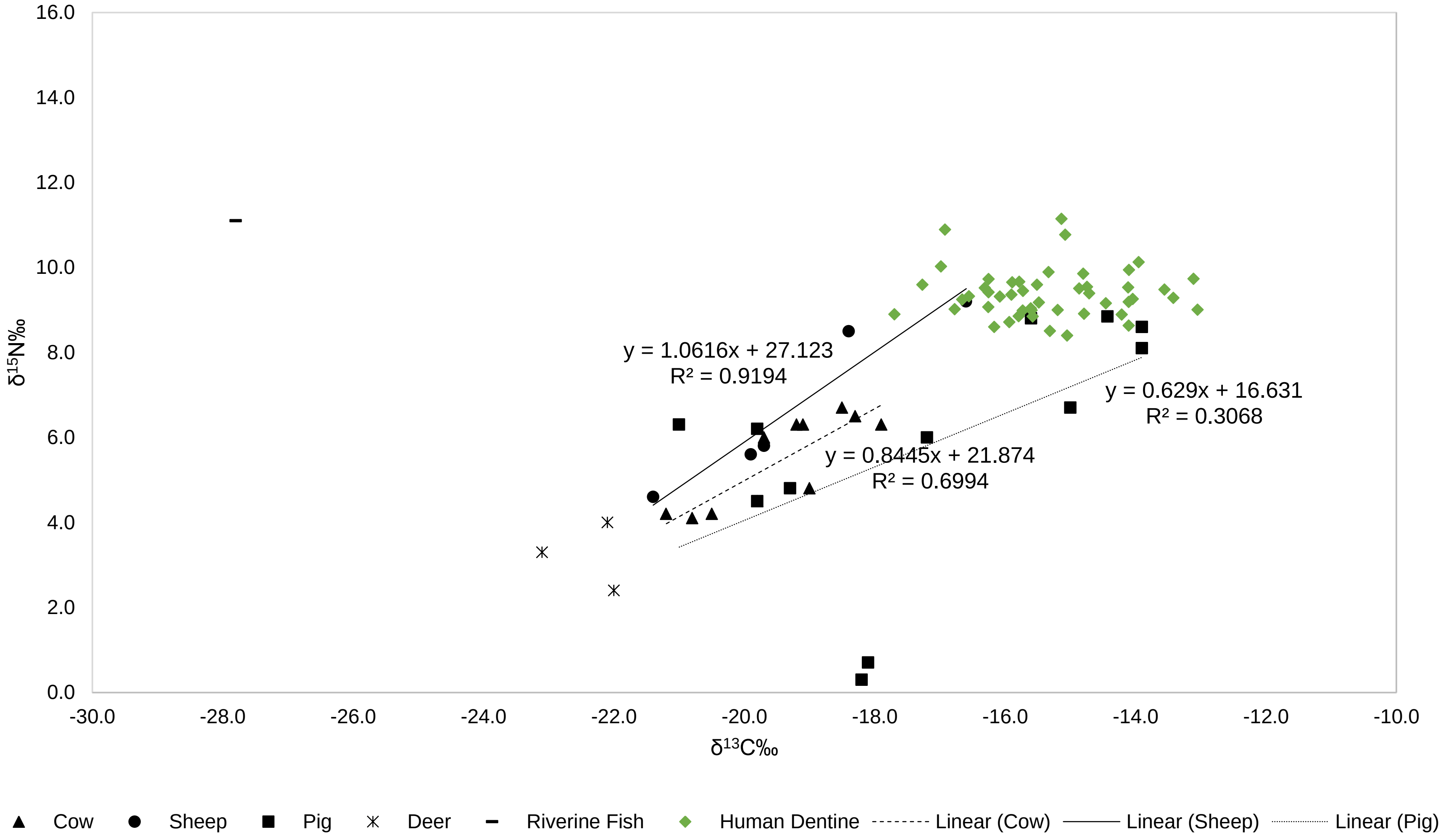


Figure 6.2. A plot of $\delta^{13}C$ and $\delta^{15}N$ values from the ENTRANS animal baseline and human dentine collagen samples from the whole study area

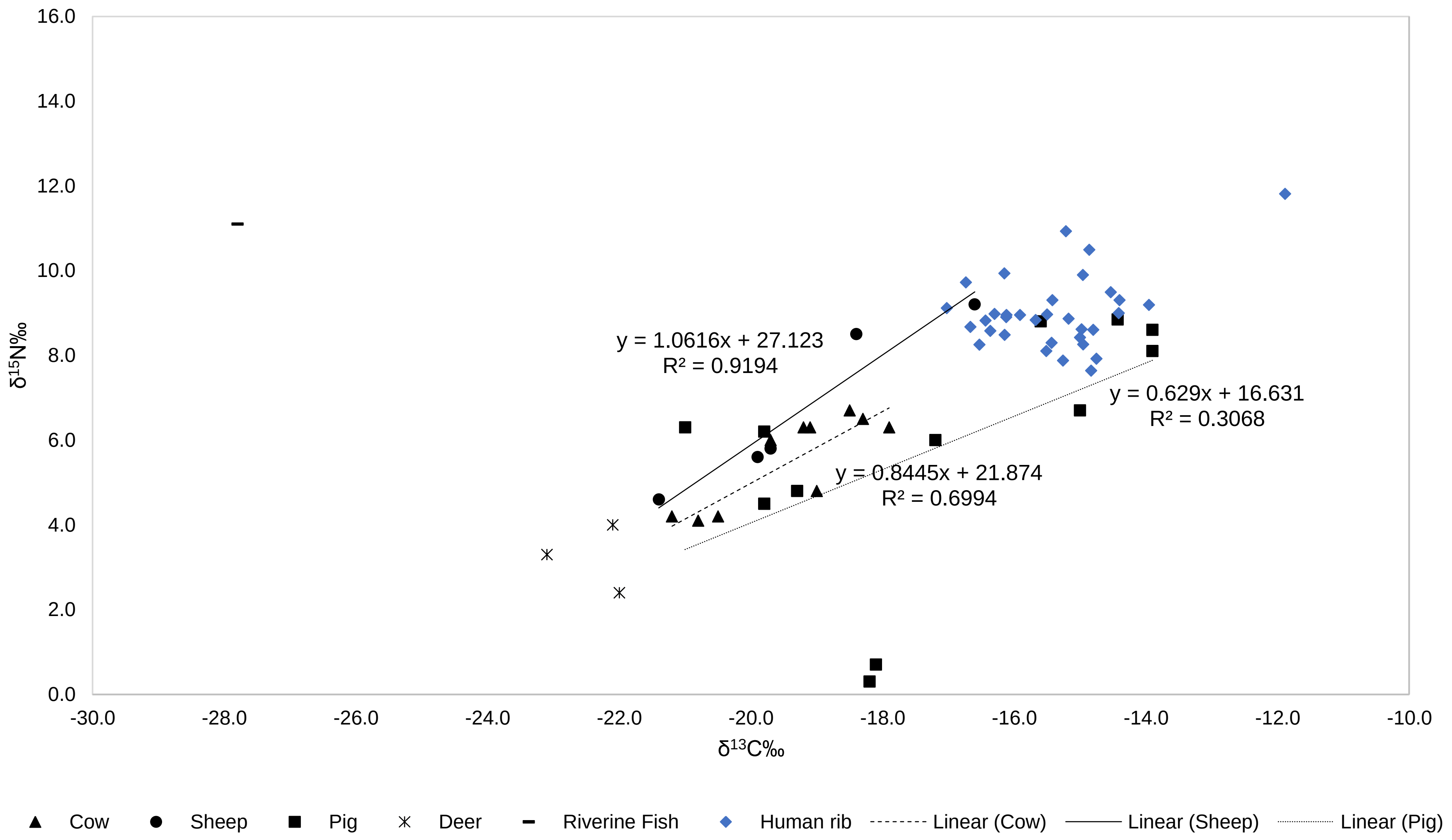


Figure 6.3 A plot of $\delta^{13}C$ and $\delta^{15}N$ values from the ENTRANS animal baseline and human rib collagen samples from the whole study area

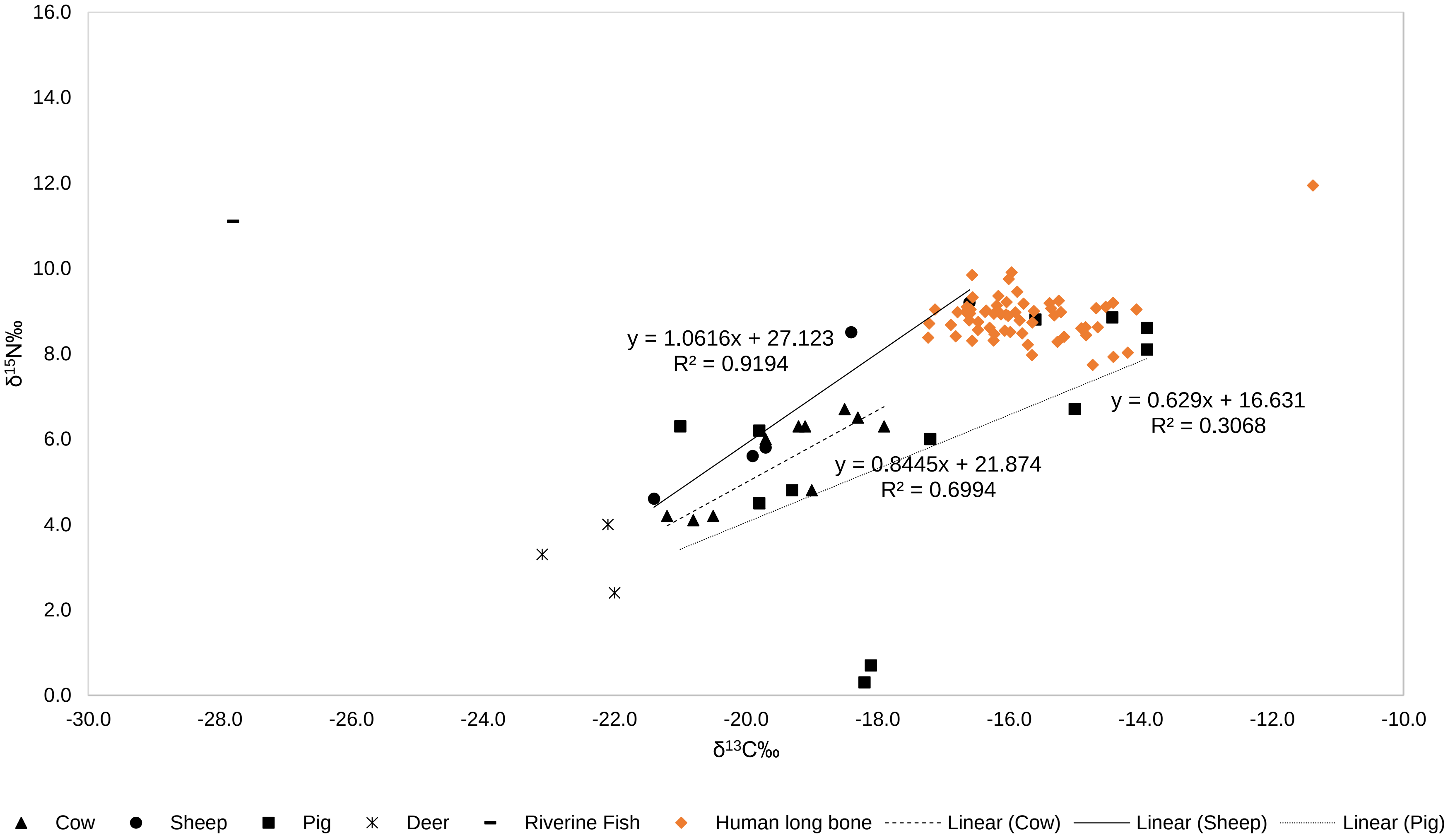


Figure 6.4 A plot of $\delta^{13}C$ and $\delta^{15}N$ values from the ENTRANS animal baseline and human long bone collagen samples from the whole study area

6.2 Human bulk collagen analysis

The primary human carbon and nitrogen stable isotope datasets were produced from the bulk collagen of long bones (principally femur, but rarely where this bone was not available, other elements including the tibia, ulna and humerus were selected), ribs and apex dentine. Where possible, all three elements were sampled as a means of tracking inter and intra-individual isotopic homogeneity or heterogeneity, in search of dietary distinctions based on age, sex, or social structure.

6.2.1 Multi-scalar analysis of bulk collagen carbon and nitrogen isotope ratios

Site, inter and intra-site level trends could only be investigated using basic descriptive statistics because of the small sample sizes of each cemetery (See Chapter 3. For this reason, in addition to carbon and nitrogen isotope plots, box and whisker plots have been created to compare sites and $\delta^{13}C$ and $\delta^{15}N$ values obtained from the collagen of different skeletal elements. Tables have also been created to provide mean and median values as well as the interquartile range (IQR). The interquartile range was calculated by subtracting the value of the first quartile (Q1) from the value of the third quartile (Q3). The interquartile range represents approximately half of the data, while the two whiskers represent approximately a quarter of the data each. The size of the box and the length of each whisker reflect the spread within each fraction of the data.

6.2.2 Results of bulk carbon and nitrogen isotope analysis on apex dentine, rib and long bone collagen

The results of carbon and nitrogen isotope analysis of multiple bone and tooth elements are presented in Figures 6.5 and 6.6. Minimum and maximum $\delta^{13}C$ and $\delta^{15}N$ values for the whole ENTRANS human dataset can be found in Table 6.2 as well as the calculated means and standard deviation for each skeletal element type. The human $\delta^{13}C$ and $\delta^{15}N$ results from different tissues have also been plotted alongside the animal baseline in Figures 6.2 to 6.4.

Element	*Min $\delta^{13}C$ ‰*	*Min $\delta^{15}N$ ‰*	*Max $\delta^{13}C$ ‰*	*Max $\delta^{15}N$‰*	*Mean $\delta^{13}C$ ‰*	*Mean $\delta^{15}N$‰*	*Stdev $\delta^{13}C$ ‰*	*Stdev $\delta^{15}N$ ‰*
Apex dentine (n=47)	-17.7	8.4	-13.0	11.1	-15.3	9.4	1.1	0.6
Rib (n=32)	-17.0	7.6	-11.4	11.9	-15.3	9.1	1.2	1.0
Long bone (n=60)	-17.2	7.7	-14.1	9.9	-15.9	8.8	0.8	0.4

Table 6.2. Minimum and maximum $\delta^{13}C$ and $\delta^{15}N$ values, with means and standard deviations of the regional human data, by skeletal element

The $\delta^{13}C$ and $\delta^{15}N$ values produced as part of this study are strongly indicative of a terrestrial-based diet, with a focus on a mix of C3 and C4 plants, probably millet, with the addition of herbivorous animal protein (Tieszen 1991; Richards 2003; Tykot 2004; Hedges and Reynard 2007). When the $\delta^{13}C$ values of bulk collagen samples are compared at a regional scale, values appear to cluster consistently between ~-17‰ and ~-13‰, and $\delta^{15}N$ values ranging between ~8‰ ~10‰. There are some notable outliers for both $\delta^{13}C$ and $\delta^{15}N$ values, with some $\delta^{13}C$ values as high as -11.4‰, and $\delta^{15}N$ values reaching 12.4‰.

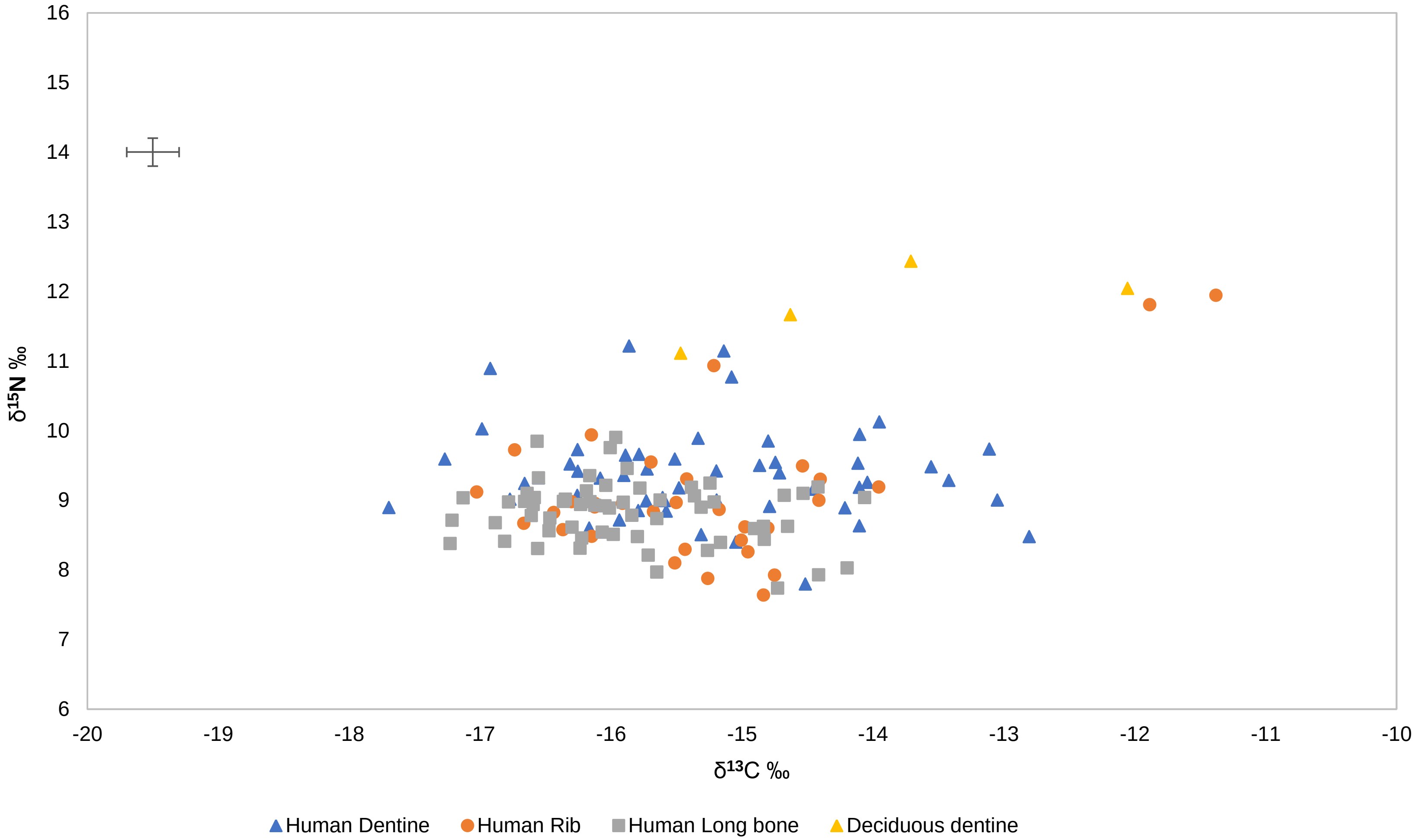


Figure 6.5. A plot of $\delta^{13}C$ and $\delta^{15}N$ values from the whole ENTRANS human dataset, including dentine (apex dentine and whole tooth mean values (WTM)), rib and long bone collagen samples. The error bars represent a standard error of 0.2‰

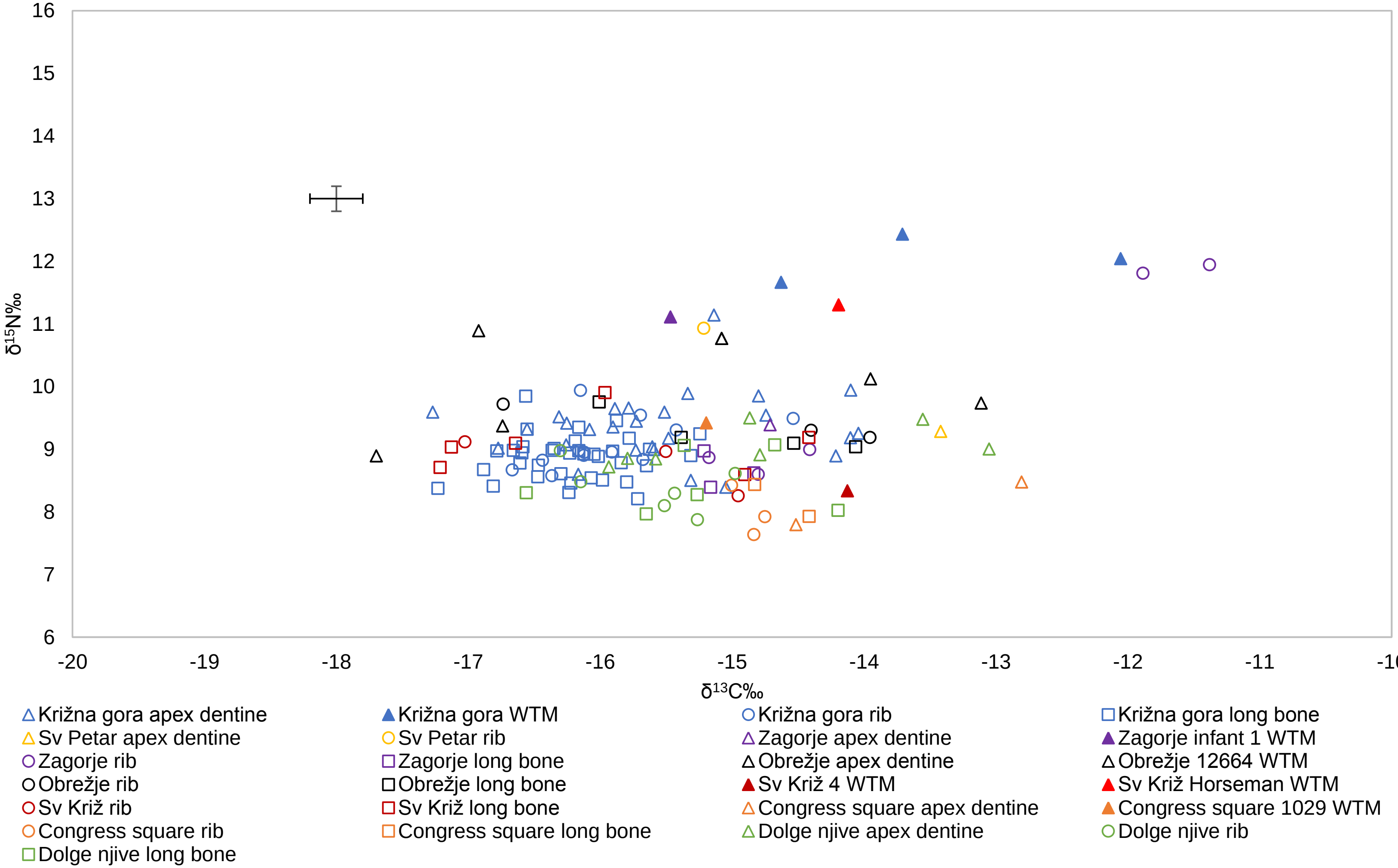


Figure 6.6. A plot of $\delta^{13}C$ and $\delta^{15}N$ values from the whole ENTRANS human dataset, including dentine (apex dentine and whole tooth mean values (WTM)), rib and long bone collagen samples. Values have been colour coded by the site. The error bars represent a standard error of 0.2‰.

6.2.3 Kruskal-Wallis ANOVA

The results of a Kruskal-Wallis ANOVA test for significant differences between skeletal collagen categories (apex dentine, rib, long-bone) are presented in Figures 6.7 and 6.8. A significant difference was detected between medians of the three groups, for the carbon and nitrogen isotope ratios. When the pairwise comparisons are observed (Figures 6.9 and 6.10), significant differences between the apex dentine category and both the rib and long-bone categories are identified, for $\delta^{15}N$ values, and between the long-bone and apex-dentine categories for $\delta^{13}C$ values. No significant difference is identified between the rib and long-bone categories for either isotope. This suggests that there may have been a difference between childhood and adult protein consumption. Alternatively, the differential rates of bone turnover could be influencing isotope ratios, as dentine forms much faster than bone collagen remodels, and does not regenerate (Parfitt 2002; Hedges et al. 2007). Consequently, shorter periods of dietary variation (e.g. seasonality) could be affecting apex dentine values more prominently. These factors are addressed throughout the remainder of this chapter.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of δ15N is the same across categories of Element.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure 6.7 The results of a Kruskal-Wallis ANOVA test to investigate the distribution of nitrogen isotope ratios of different skeletal elements (apex dentine, rib and long-bone collagen).

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of δ13C is the same across categories of Element.	Independent-Samples Kruskal-Wallis Test	.028	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

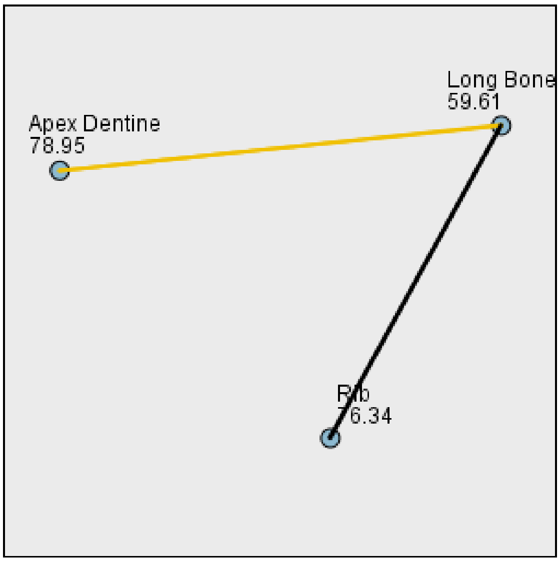
Figure 6.8. The results of a Kruskal-Wallis ANOVA test to investigate the distribution of carbon isotope ratios of different skeletal elements (apex dentine, rib and long-bone collagen)

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
Long Bone-Rib	-4.058	8.788	-.462	.644	1.000
Rib-Apex Dentine	31.798	9.201	3.456	.001	.002
Long Bone-Apex Dentine	35.856	7.820	4.585	.000	.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.

Figure 6.9 *The results of a pairwise Kruskal-Wallis ANOVA test to investigate the distribution of nitrogen isotope ratios of different skeletal elements (apex dentine, rib and long-bone collagen)*

Pairwise Comparisons of Element



Each node shows the sample average rank of Element.

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
Long Bone-Rib	-16.735	8.809	-1.900	.057	.172
Long Bone-Apex Dentine	19.338	7.839	2.467	.014	.041
Rib-Apex Dentine	2.603	9.223	.282	.778	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.

Figure 6.10 The results of a pairwise Kruskal-Wallis ANOVA test to investigate the distribution of nitrogen isotope ratios of different skeletal elements (apex dentine, rib and long-bone collagen)

6.2.4 Comparison with animal isotopic baseline

When the human carbon and nitrogen isotope data is compared to the animal baseline, the predicted trophic level shift of c.2-5‰ between humans and most herbivores is present (Ambrose 1991; Hedges and Reynard 2007). This supports the interpretation that humans were ingesting herbivorous animal protein, either dairy or meat. It could be argued that pig meat did not make up a significant proportion of human diet, as many pigs and humans have plotted in a similar position (Figures 6.1 to 6.4). However, as pigs are also seen to plot within the ranges produced by cattle and sheep/goats, this is more difficult to assess.

Freshwater resources may not have made up a significant proportion of the human diet, as the freshwater fish $\delta^{13}C$ values are significantly more negative than human values. However, more samples would be needed to clarify this situation further.

6.2.5 Outliers

Anomalous values have been produced from primarily non-adult remains. The most obvious outliers in both $\delta^{13}C$ and $\delta^{15}N$ values are two infants from Zagorje ob Savi. When plotted against the other individuals buried at this cemetery (Figure 6.11) and with a site-specific animal baseline, $\delta^{15}N$ values are between 3‰ and 3.5‰ above that of the adult rib mean of 8.8‰ +/- 0.2‰, while their $\delta^{13}C$ values are ~3‰ above the adult mean of -14.8‰ +/- 0.4‰. This is strongly indicative of a different diet to the rest of the cemetery group, which is interesting, as Infant 1 was c.7 months old and Infant 2 probably younger still at the time of death. This being the case, it would be expected that these infants would be breastfeeding and, therefore, their isotope ratios would reflect the isotopic composition of their mother's diet (with a potential trophic shift) (Millard 2000; Fuller et al. 2006; Jay et al. 2008). These outliers, with a focus on Infant 1, are discussed further in Section 6.3 and Chapter 7 using other investigative methods, which have proven to be more informative.

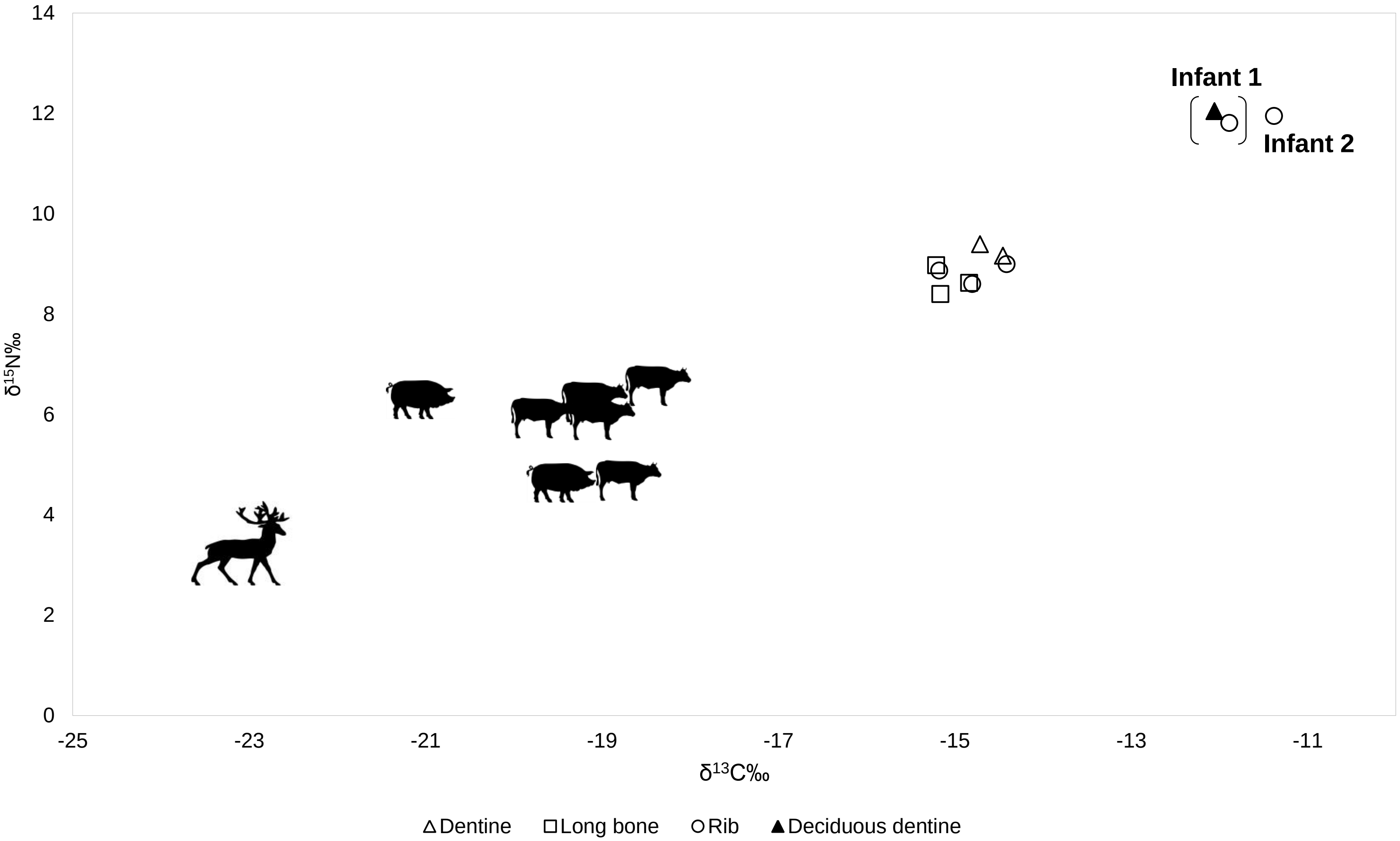


Figure 6.11. A plot of $\delta^{13}C$ and $\delta^{15}N$ values of animals and humans from the cemetery site of Zagorje ob Savi. There is a clear separation in both the $\delta^{13}C$ and $\delta^{15}N$ values of the adult and infant remains.

When different skeletal elements from the whole human dataset are compared in box and whisker plots (Table 6.3 and Figures 6.12 and 6.13), there is a high incidence of overlap among the three element categories, in both $\delta^{13}C$ and $\delta^{15}N$ values. Overall, the range of $\delta^{13}C$ values is greater than that of the $\delta^{15}N$ values. This consistently broader spread of $\delta^{13}C$ values, with all $\delta^{13}C$ values greater than -17‰, indicates that all the individuals included in this study were ingesting a mix of C3 and C4 plants, with some consuming a significant amount of C4 plants, probably millet (Tykot 2004; Lightfoot et al. 2013; Lightfoot et al. 2014b).

	Apex dentine (n=47)		*Rib (n=32)*		*Long bone (n=60)*	
	$\delta^{13}C$‰	$\delta^{15}N$‰	$\delta^{13}C$‰	$\delta^{15}N$‰	$\delta^{13}C$‰	$\delta^{15}N$‰
Median	-15.5	9.3	-15.4	9.0	-16.0	8.9
IQR	1.5	0.6	1.3	0.7	1.2	0.6
Mean	-15.3	9.4	-15.3	9.1	-15.9	8.8

Table 6.3. Median, mean, interquartile ranges and standard deviation $\delta^{13}C$ and $\delta^{15}N$ values for the whole human dataset, separated by skeletal element sampled

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The similarity in ranges of isotopic ratios between skeletal element categories suggests that, at a regional scale, the isotopic composition of dietary protein was not highly variable among populations, life stages, or between the sexes.

A slightly increased variability can be observed in the apex dentine category in relation to the rib and long bone categories. This range of $\delta^{13}C$ values from apex dentine may indicate a more variable consumption of C4 plants (millet) during childhood, whilst the tooth was forming, than during adulthood (represented by rib and long bone samples). Alternatively, and perhaps more likely, this increased variability could be the result of different tissue turnover and formation rates (Hedges et al. 2007). As the dentine is actively forming, it is more likely to be influenced by short, sharp shifts in the diet (e.g. seasonal variability) than the other two tissues, which represent a much longer average of dietary consumption (Beaumont et al. 2013a; Beaumont et al. 2013b; Beaumont et al. 2015).

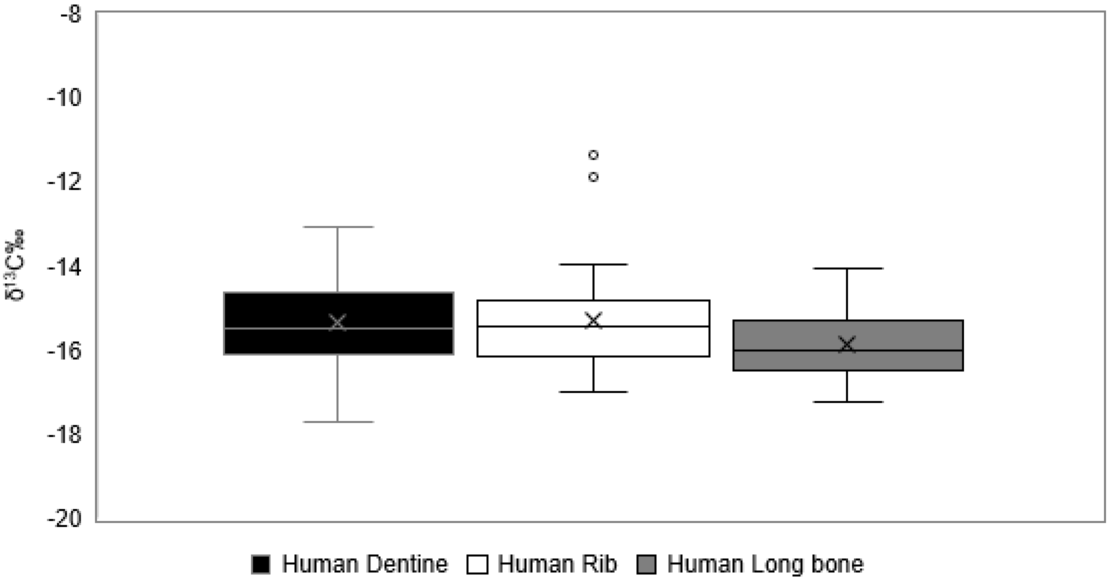

Figure 6.12. Box and whisker plot comparing regional $\delta^{13}C$ values by skeletal element: Dentine (n=47); Rib (n=32); Longbone (n=60). The two outlying human rib samples are from the 2 infants buried at Zagorje ob Savi. There is an observable isotopic variability within and between the different categories. The largest variability is observed in the apex dentine category. This is probably reflecting the variable consumption of C4 plants.

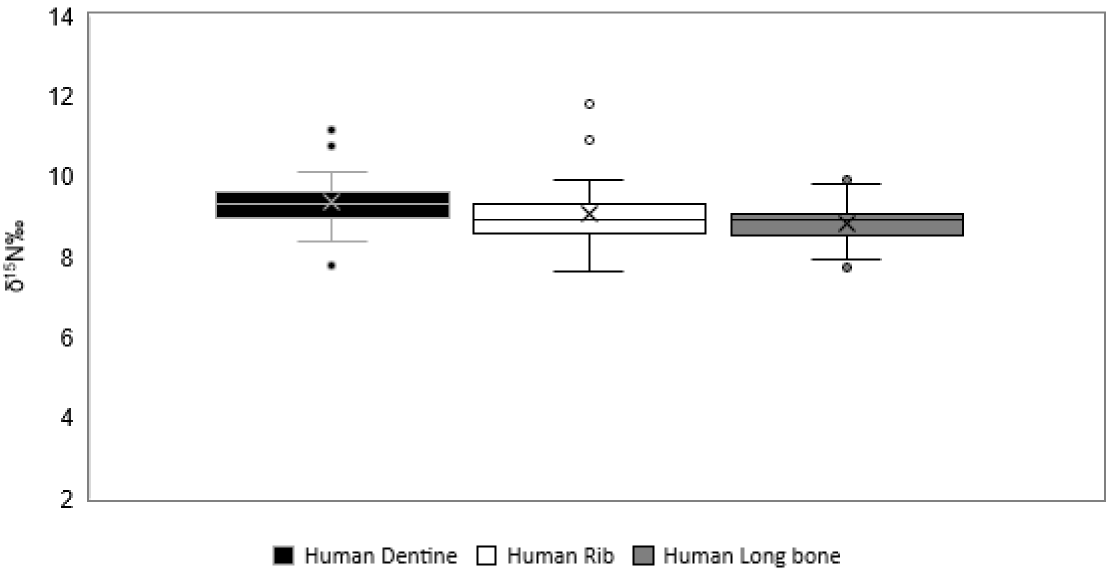

Figure 6.13. Box and whisker plot comparing regional $\delta^{15}N$ values by skeletal element: Dentine (n=47); Rib (n=32); Longbone (n=60). The dentine outliers are Ljubljana Congress Square, Obrežje 12664 and Obrežje 3043. The outlying human rib samples are from the 2 infants buried at Zagorje ob Savi. The long bone outliers are Grofove njive 241 and Sv Križ 4. Overall, there is little isotopic variability within or between categories.

Inter-site trends

To investigate whether there was any dissimilarity in carbon and nitrogen isotope ratios between different cemetery sites, they have been separated and compared in this section of the chapter. Any disparities in the $\delta^{13}C$ and $\delta^{15}N$ values between cemetery sites would indicate a variance in subsistence strategies between different communities (Richards et al. 1998; Müldner and Richards 2005).

When ranges of delta values produced from different skeletal elements are also divided by site (Figure 6.14 to 6.19), inter-site variation in $\delta^{13}C$ values appears to be highlighted. However, this is more likely the result of small and inconsistent sample sizes, than a difference in community diet, as the broadest ranges are associated with the largest sample sizes.

When compared to the regional scale interpretation, a similar level of increased variability in $\delta^{13}C$ values in comparison to $\delta^{15}N$ values can be observed between sites, again, with the widest spread of $\delta^{13}C$ values observed in the apex dentine category. As has been demonstrated in the box and whisker plots for rib and long bone remains (Tables 6.4 to 6.6 and Figures 6.14 to 6.19), site-specific isotope ratios overlap, with similar ranges of ~2‰ in $\delta^{13}C$ values, and generally <1‰ in $\delta^{15}N$ values.

The site of Obrežje provides the least consistent $\delta^{13}C$ values in relation to other sites, but this is likely because of the elongated chronology and unrepresentative nature of this cemetery (see Section 2.2). This interpretation is revisited later in this chapter, with the assistance of enamel carbonate analysis.

Overall $\delta^{13}C$ and $\delta^{15}N$ values from apex dentine, rib and long bone samples representing different communities are also relatively consistent at the inter-site level, again giving little indication of dietary differences based on age, sex, or status. Therefore, no significant difference can be interpreted regarding the dietary practices among different communities inhabiting this landscape.

Apex dentine	Mean		Standard deviation		IQR	
	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$
Križna gora (n=25)	-15.5	9.3	0.8	0.4	1.1	0.5
Obrežje (n=5)	-15.4	10.1	1.9	0.8	2.9	1.1
Dolge njive (n=7)	-14.8	9.0	1.1	0.3	1.5	0.4
Grofove njive (n=3)	-16.6	9.7	0.4	0.4	0.3	0.4
Metlika (n=2)	-14.7	9.3	0.8	0.4	0.5	0.3
Zagorje (n=2)	-14.6	9.3	0.2	0.2	0.1	0.1
Sv Križ (n=2)	-16.2	10.4	1.5	1.1	1.0	0.8
Congress square (n=1)	-14.1	8.6	0.0	0.0	0.0	0.0
Sv Petar (n=1)	-13.4	9.3	0.0	0.0	0.0	0.0

Table 6.4. Mean, standard deviation and Interquartile ranges of Apex dentine collagen $\delta^{13}C$ and $\delta^{15}N$ for each site

Rib	Mean		Standard deviation		IQR	
	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$
Križna gora (n=10)	-15.9	9.0	0.7	0.3	0.6	0.4
Obrežje (n=3)	-15.0	9.4	1.5	0.3	1.4	0.3
Dolge njive (n=7)	-15.7	8.4	0.6	0.4	0.9	0.3
Zagorje (n=4)	-14.1	9.6	1.5	1.5	1.1	0.9
Sv Križ (n=3)	-15.8	8.8	1.1	0.5	1.1	0.4
Congress square (n=3)	-14.9	8.0	0.1	0.4	0.1	0.4
Sv Petar (n=2)	-15.0	10.7	0.2	0.3	0.2	0.1

Table 6.5 Mean, standard deviation and Interquartile ranges of Rib collagen $\delta^{13}C$ and $\delta^{15}N$ for each site

Long bone	Mean		Standard deviation		IQR	
	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$
Križna gora (n=36)	-16.2	8.9	0.4	0.3	0.7	0.4
Obrežje (n=4)	-15.0	9.3	0.9	0.3	1.1	0.2
Dolge njive (n=6)	-15.2	8.4	0.8	0.4	0.8	0.3
Sv Križ (n=6)	-16.0	9.1	1.2	0.5	1.8	0.4
Zagorje (n=3)	-13.9	9.8	2.2	1.9	1.9	1.8
Grofove njive (n=2)	-15.4	8.5	0.9	1.0	0.6	0.7
Congress square (n=2)	-14.6	8.2	0.3	0.4	0.2	0.1
Metlika (n=1)	-14.7	8.6	0.0	0.0	0	0

Table 6.6 Mean, standard deviation and Interquartile ranges of Long bone collagen $\delta^{13}C$ and $\delta^{15}N$ for each site

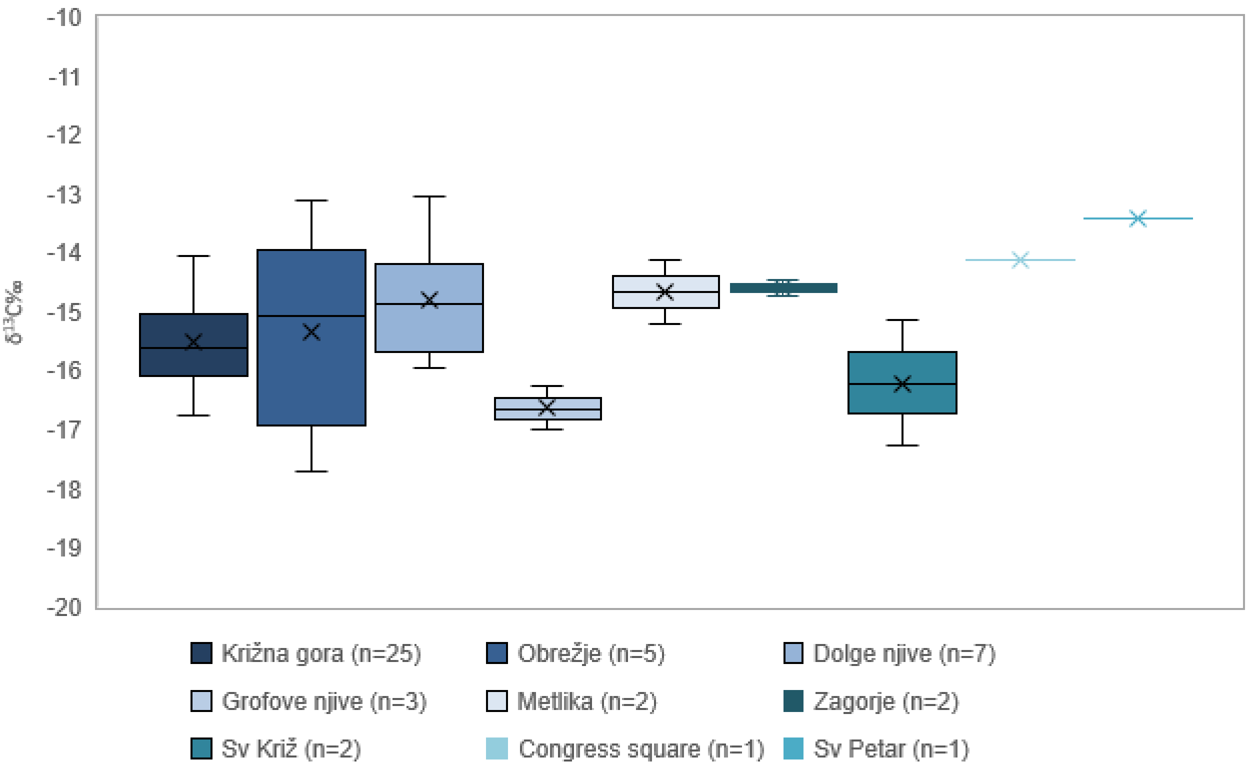

Figure 6.14. Box and whisker plot comparing dentine $\delta^{13}C$ values, separated for inter-site comparison. There is an observable isotopic variability within and between the different sites. This is probably reflecting the variable consumption of C4 plants. Contains non-adult (died in childhood) values.

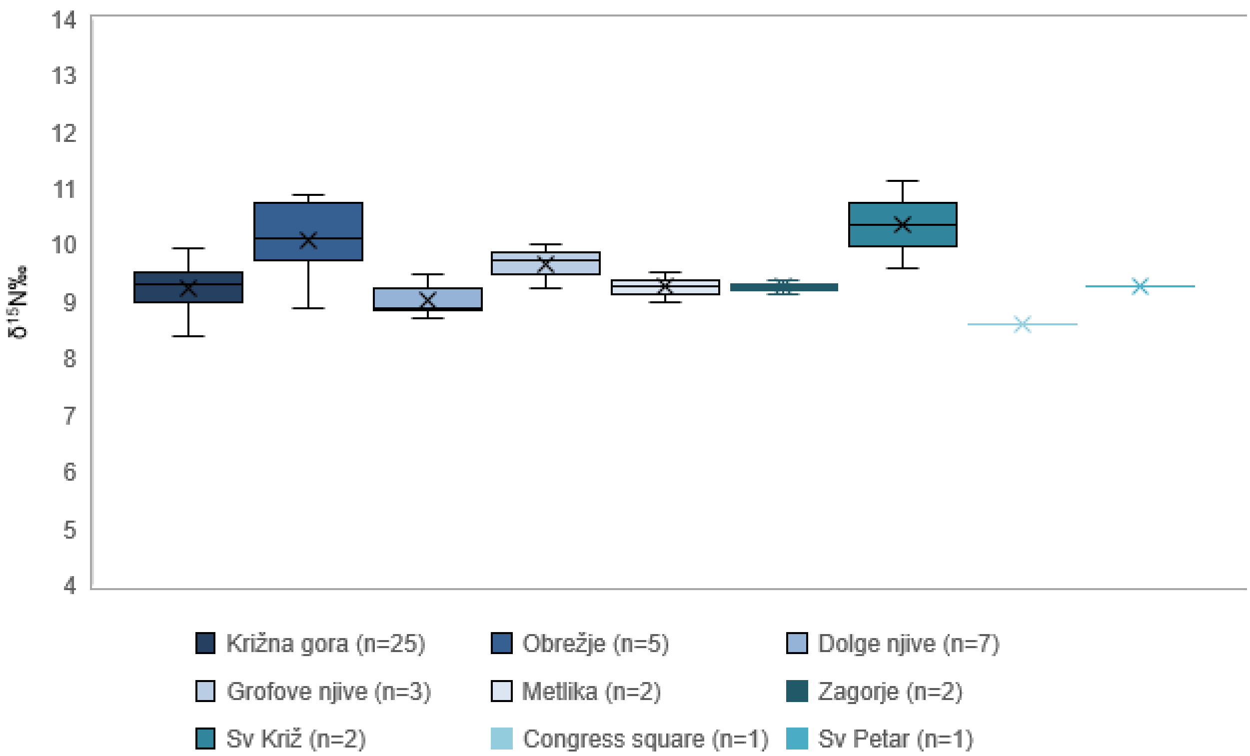

Figure 6.15. Box and whisker plot comparing dentine $\delta^{15}N$ values, separated for inter-site comparison. There is a similar level of isotopic variability between sites. Contains non-adult (died in childhood) values.

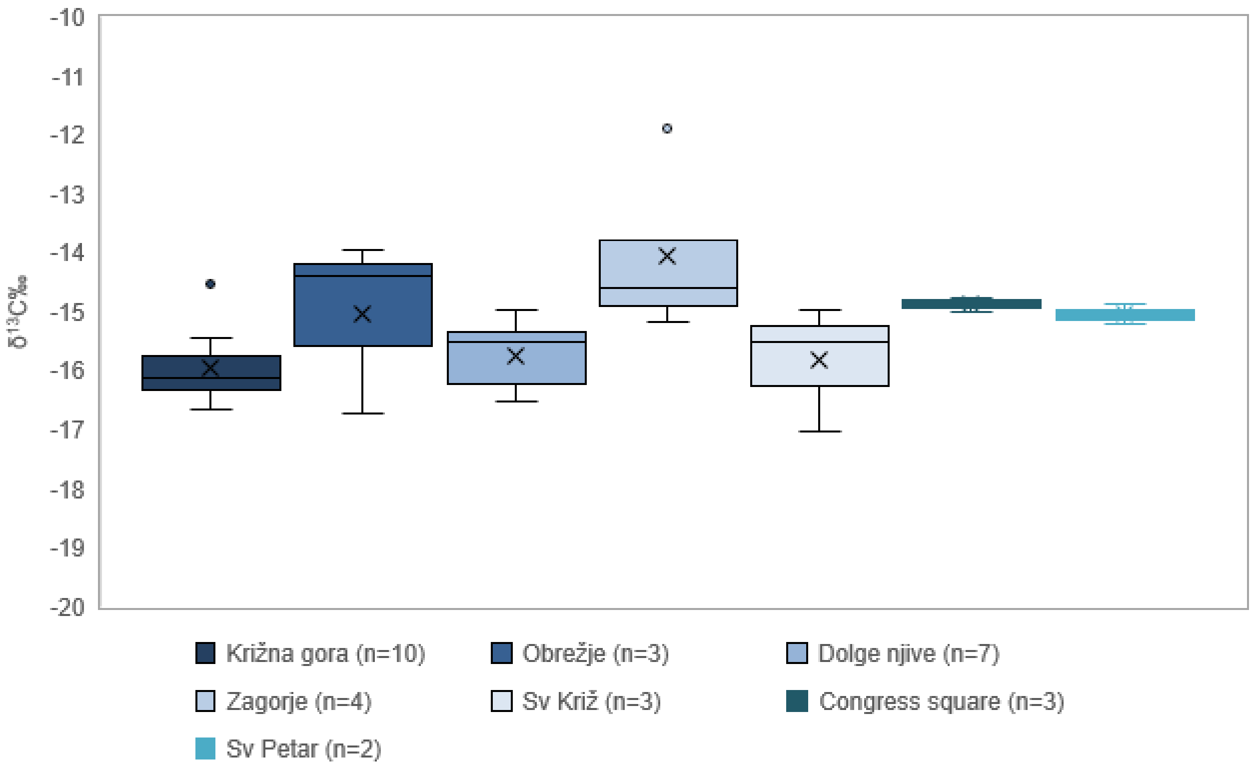

Figure 6.16. Box and whisker plot comparing rib $\delta^{13}C$ values, separated for inter-site comparison. There is an observable isotopic variability within site-based data sets, but less so between the different sites. This is probably reflecting the variable consumption of C4 plants. Contains non-adult values.

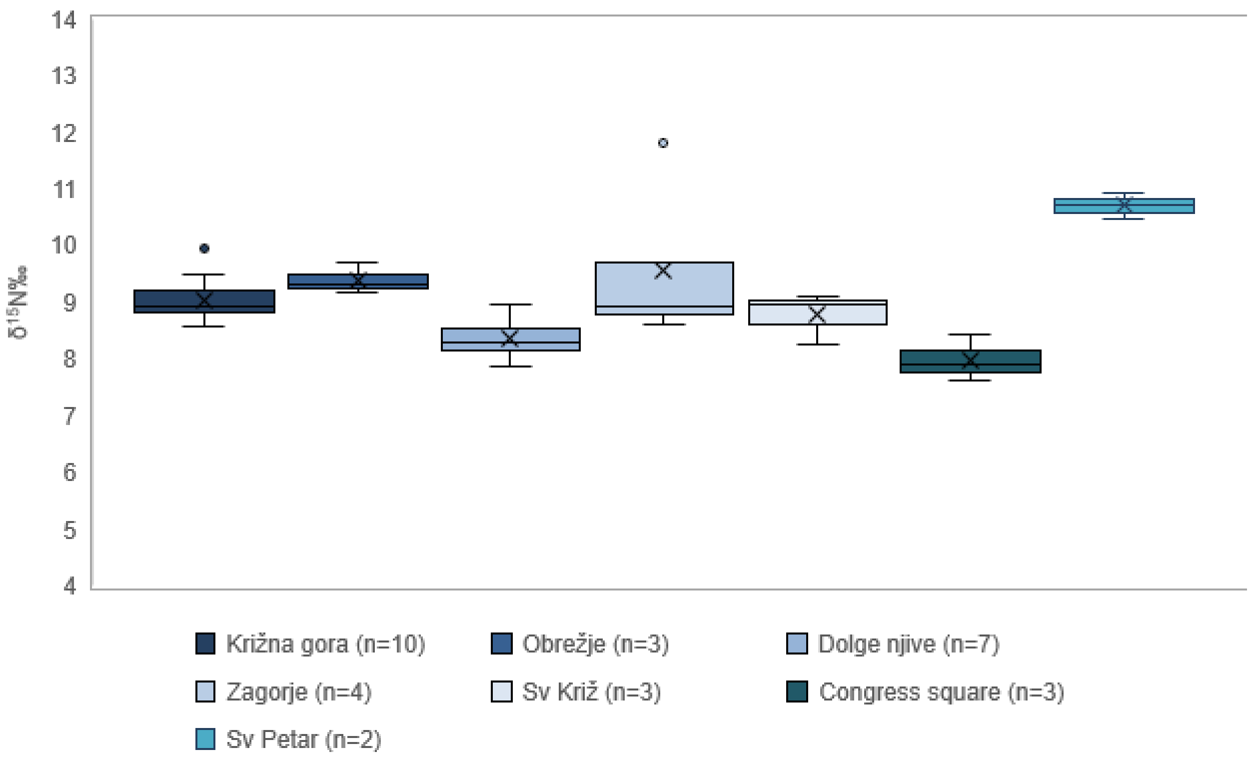

Figure 6.17. Box and whisker plot comparing rib $\delta^{15}N$ values, separated for inter-site comparison. There is a similar level of isotopic variability between sites. Contains non-adult values.

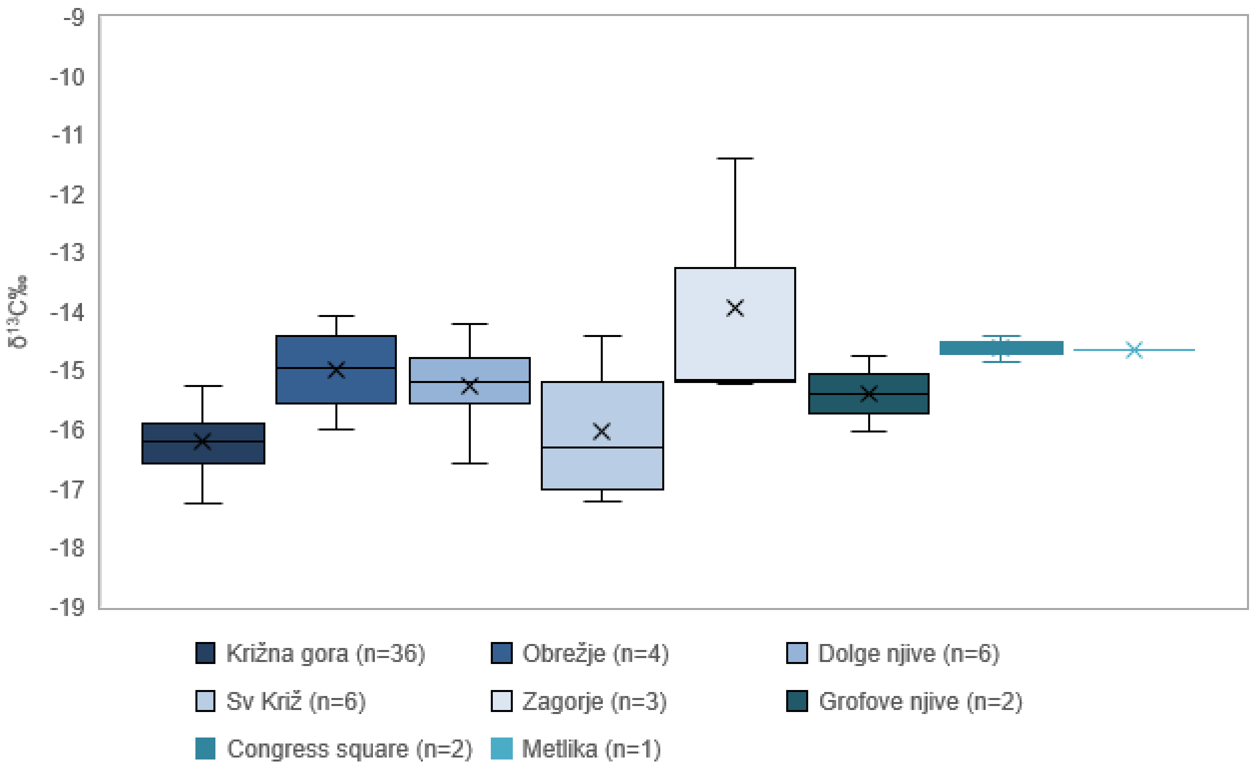

Figure 6.18. Box and whisker plot comparing long bone $\delta^{13}C$ values, separated for inter-site comparison. There is an observable isotopic variability within and between the different sites. This is probably reflecting the variable consumption of C4 plants. Contains non-adult values.

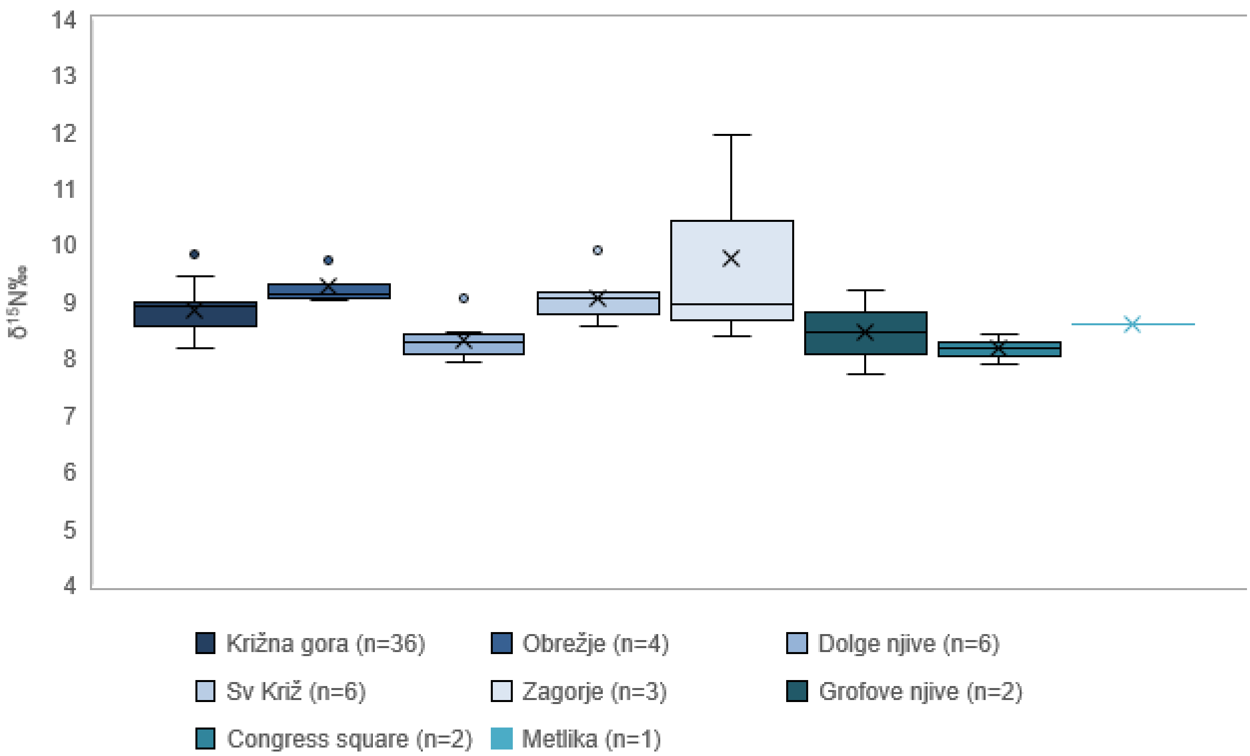

Figure 6.19. Box and whisker plot comparing long bone $\delta^{15}N$ values, separated for inter-site comparison. There is a similar level of isotopic variability between sites. Contains non-adult values.

Intra-site trends

In this section, ranges of carbon and nitrogen isotope ratios are explored at the cemetery scale. As has already been demonstrated, there is little evidence for isotopic variation among cemetery sites. This section aims to investigate whether there are any abnormalities or variation within a single cemetery. To do this, the cemeteries of Križna gora, Dolge njive and Obrežje were selected as they represent key sites throughout the thesis. For the most part, similar trends are observed here as were identified at the broader regional and inter-site scales.

Križna gora

The cemetery site at Križna gora constitutes the largest carbon and nitrogen isotope dataset available to the ENTRANS project. From this site, 27 individuals could be sampled for apex dentine, 12 for rib, and 36 for long bone collagen.

As can be observed in Figures 6.20 and 6.21, the collagen samples taken from the individuals buried at this cemetery have produced relatively constrained ranges of $\delta^{13}C$ and $\delta^{15}N$ values, with very similar interquartile ranges, means and medians (see Table 6.7). The $\delta^{13}C$ values exhibit a larger range than the $\delta^{15}N$ values. The largest spread of both isotope ratios was identified in the apex dentine category, as already expected following the examination of both regional and inter-site scale data.

	Apex dentine (n=24)		Rib (n=10)		Long bone (n=36)	
	$\delta^{13}C$‰	$\delta^{15}N$‰	$\delta^{13}C$‰	$\delta^{15}N$‰	$\delta^{13}C$‰	$\delta^{15}N$‰
Median	-15.7	9.3	-16.1	9.0	-16.2	8.9
IQR	1.0	0.6	0.9	0.5	0.4	0.7
Mean	-15.6	9.3	-16.0	9.0	-16.2	8.9
Standard deviation	0.8	0.4	0.6	0.4	0.4	0.3

Table 6.7. median, mean values, interquartile ranges and standard deviation $\delta^{13}C$ and $\delta^{15}N$ values for the Križna gora human dataset, separated by skeletal element sampled.

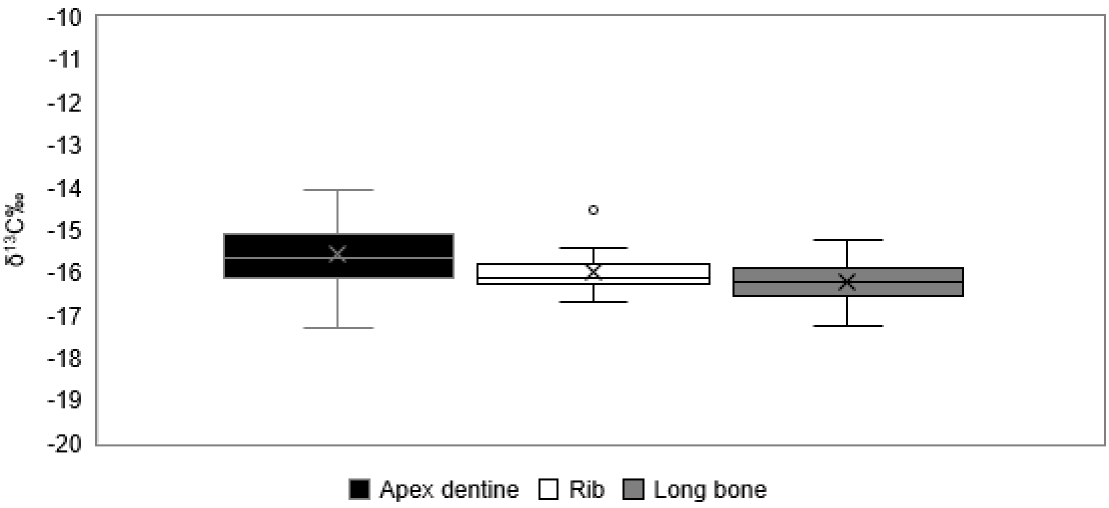

Figure 6.20. Box and whisker plot of $\delta^{13}C$ values from Križna gora by skeletal element: Dentine (n=24); Rib (n=10); Long bone (n=36). The single outlier identified in the rib category is grave 85.

From the $\delta^{13}C$ values, one outlier could be identified from the rib category. This is Grave 85. Although they are an outlier in this category, the value itself is not greatly dissimilar to the whole cemetery dataset, falling within the range of the apex dentine samples. This result is probably due to the fact that the rib group contains the least number of collagen samples relative to the other two categories. The individual buried in Grave 85 could also be sampled for their dentine and long bone collagen, and the results from these samples were not found to be anomalous.

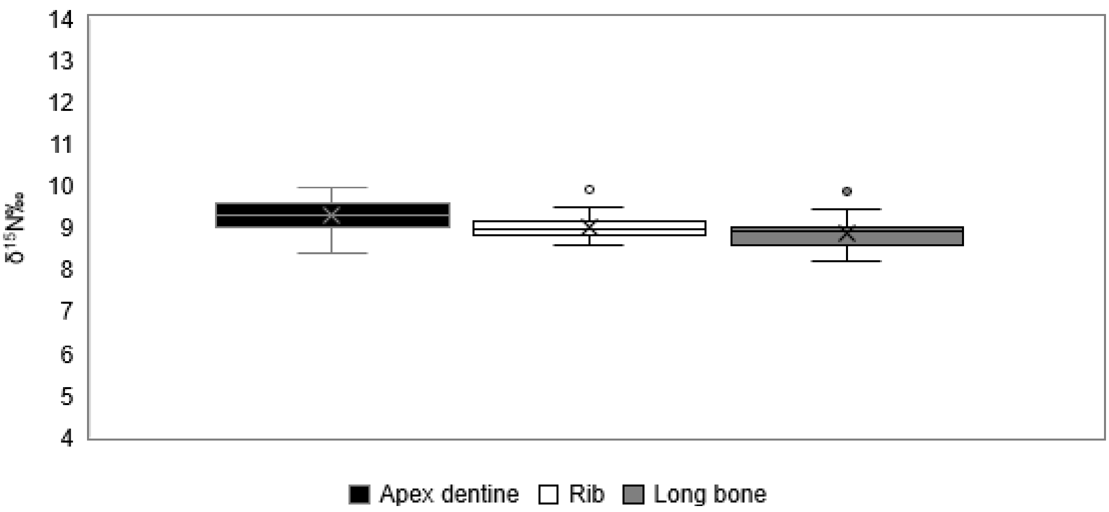

Figure 6.21. Box and whisker plot of $\delta^{15}N$ values from Križna gora by skeletal element Dentine (n=24); Rib (n=10); Long bone (n=36). The two outliers identified in the apex dentine category the long bone category is grave 73

The $\delta^{15}N$ values, displayed in Figure 6.21, demonstrate that there are very similar delta values produced from the three categories of tissue. This shows that all individuals from this cemetery site were likely consuming a similar quantity of terrestrial protein, from a similar source, regardless of age (Hedges and Reynard 2007).

Two outliers have been identified in the apex dentine and from the long bone category, both of which were produced by the individual buried in Grave 73. It was not possible to collect a tooth from this individual for dentine collagen. Although this individual has displayed high $\delta^{15}N$ values relative to the other samples within each respective category, they still fall within the upper range of the apex dentine samples. It is unlikely that this individual followed a significantly different subsistence strategy.

Inter-individual isotopic variation

When the carbon and nitrogen isotope ratios obtained from multiple skeletal elements of a single individual buried at Križna gora are compared, as has been done in Figures 22 and 23, very little variation can be identified between Long bone and Rib collagen samples. $\delta^{13}C$ and $\delta^{15}N$ values from Apex dentine collagen samples are commonly higher than their associated Long bone and Rib collagen samples, which probably reflects variable childhood feeding practices, including breastfeeding and weaning (Millard 2000; Fuller et al. 2006; Jay et al. 2008; Beaumont et al. 2015). This phenomenon is addressed further in Sections 6.3 and 6.4.4.

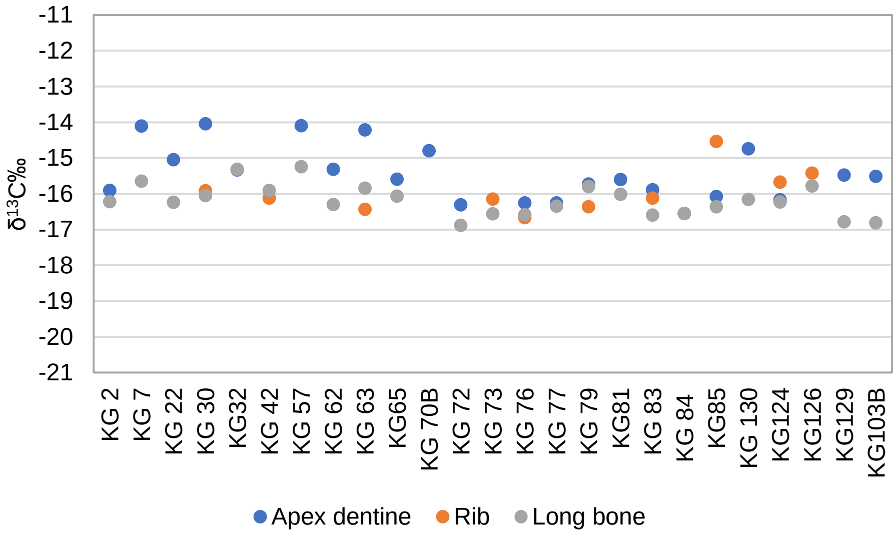

Figure 6.22. Comaprison of $\delta^{13}C$ values sampled from the same individual, Križna gora. Dentine (n=24); Rib (n=10); Long bone (n=36).

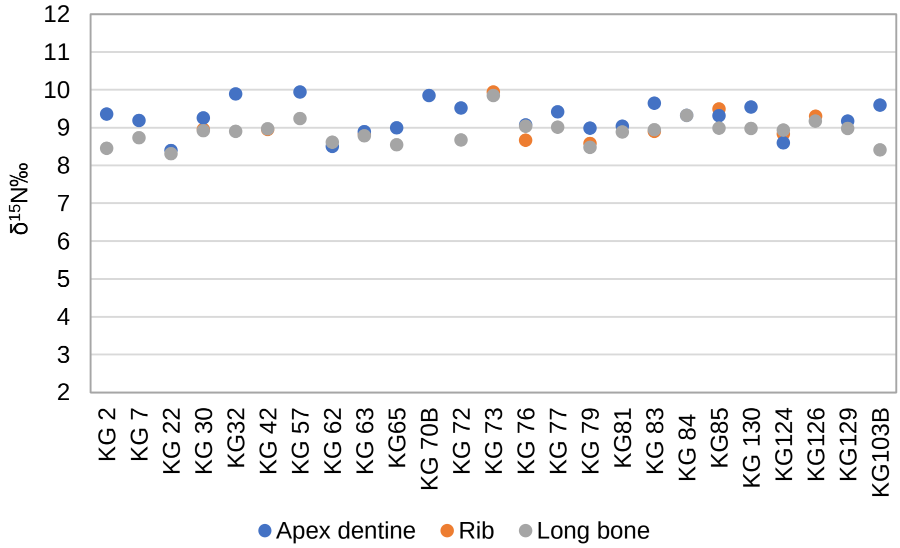

Figure 6.23 Comaprison of $\delta^{15}N$ values sampled from the same individual, Križna gora Dentine (n=24); Rib (n=10); Long bone (n=36).

These results support the argument that there is little isotopically detectable evidence for significant dietary change throughout the lifespan of single individuals buried at Križna gora. The data indicate that a diet of terrestrial protein and C4 plants, probably millet, was consumed throughout the life of this community (Tieszen 1991; Tykot 2004; Hedges and Reynard 2007).

Sex

As the Križna gora dataset provided the most samples, this cemetery has been used as a case study for the investigation of sex-based differences in carbon isotope ratios (Figures 24 and 25, Table 6.8). Very little isotopic variation was identified within the nitrogen isotope ratios between the sexes, as depicted in Figure 6.24. As the largest spread of isotope ratios was observed in the $\delta^{13}C$ values, these shall be explored in more detail.

Figure 6.25 is a box and whisker plot investigating male versus female $\delta^{13}C$ values, combining all the delta values from across the different element categories. From these Figures, it is possible to detect similar variations in $\delta^{13}C$ values between males and some females with the use of different elements.

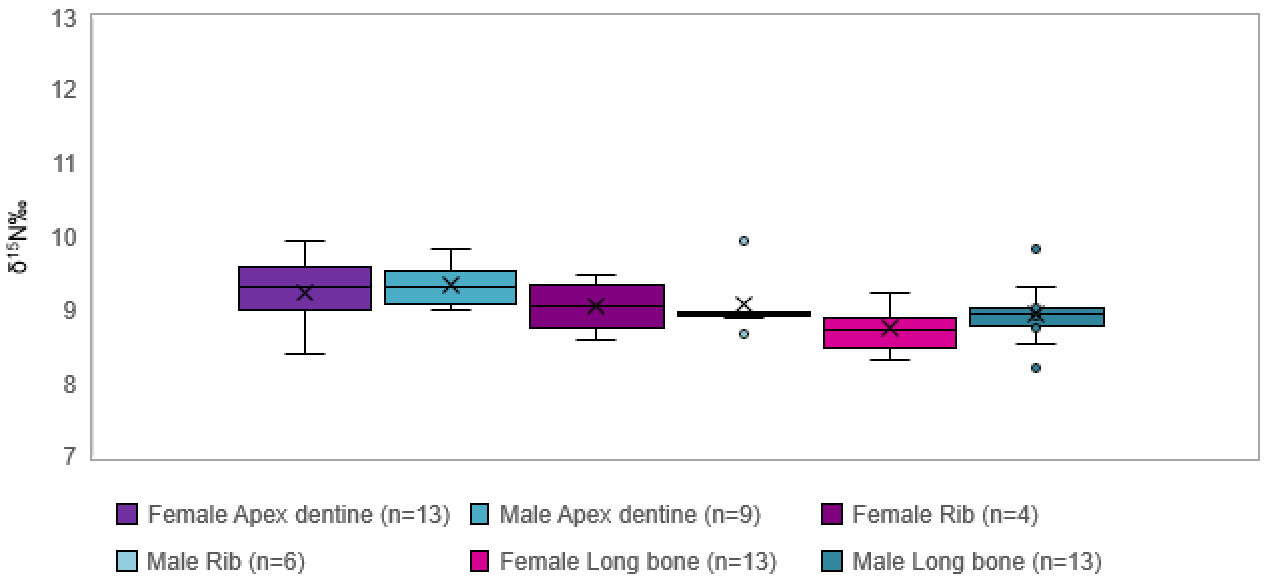

Figure 6.24. Box and whisker plot comparing $\delta^{15}N$ values of apex dentine, rib and long bone collagen, divided by sex, Križna gora. There is a similar level of isotopic variability between categories

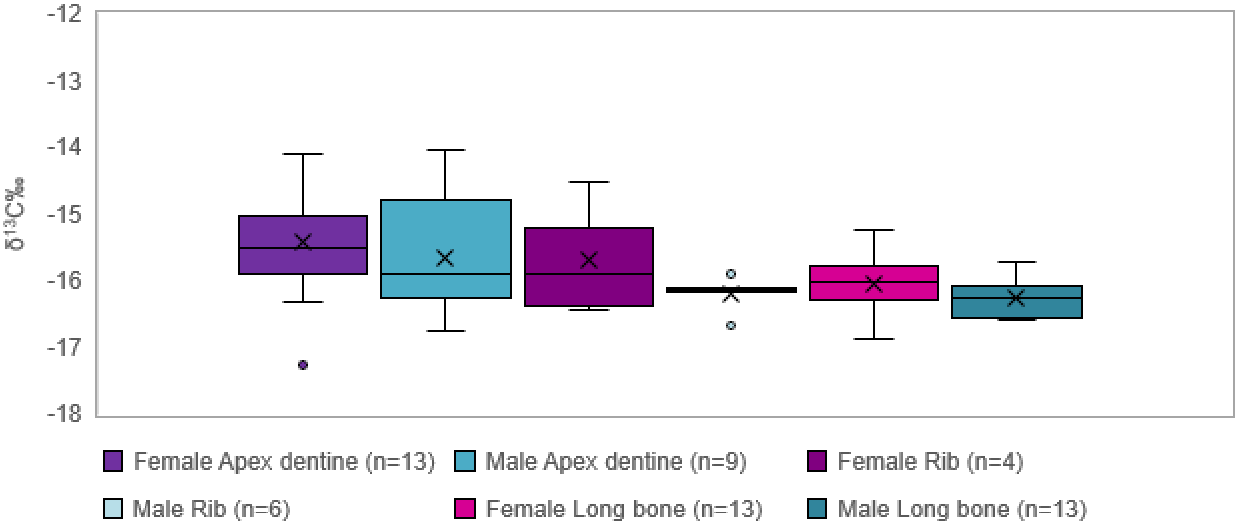

Figure 6.25. Box and whisker plot comparing δ^{13}C values of apex dentine, rib and long bone collagen, divided by sex. There is an increased isotopic variability within the female data, relative to the male data

Sex-based category	Mean δ^{13}C	Mean δ^{15}N‰	Standard deviation δ^{13}C‰	Standard deviation δ^{15}N‰
Female Apex dentine (n=13)	-15.4	9.2	0.9	0.5
Female Rib (n=4)	-15.7	9.0	0.9	0.4
Female Long bone (n=13)	-16.0	8.7	0.5	0.3
Male Apex dentine (n=9)	-15.7	9.3	0.9	0.3
Male Rib (n=6)	-16.2	9.1	0.3	0.4
Male Long bone (n=13)	-16.3	9.0	0.3	0.4

Table 6.8. The mean and median δ^{13}C values and standard deviation of for sex-based categories.

The distribution of the data also suggests that females were more commonly producing the higher δ^{13}C values from this cemetery, as roughly three-quarters (represented by the box and upper whisker) of the whole female dataset, plots above the mean and median values of the male dataset (particularly the long bone and rib collagen). This could suggest that females are more likely to produce δ^{13}C above that of males, indicative of an increased C4 signal from the female remains (Tieszen 1991; Tykot 2004). As has been demonstrated in Table 6.8, the median and mean δ^{13}C values produced by the female groups are consistently above that of the male values. However, these differences are very slight and fall within the standard error of one another. Whether this very small disparity in carbon isotope ratios translates into a meaningful difference between the sexes is less likely. For example, these small differences may just be the result of personal preference or portion size. Overall, δ^{13}C and δ^{15}N values obtained from the cemetery at Križna gora have demonstrated a high level of dietary homogeneity within the community, between the sexes and across different life stages, as represented by the different skeletal tissues sampled.

Dolge njive

The carbon and nitrogen isotope data set for Dolge njive consists of ten individuals. Seven could be sampled for dentine collagen extraction, five for rib, and six for long bone.

	Apex dentine (n=7)		Rib (n=7)		Long bone (n=6)	
	δ^{13}C‰	δ^{15}N‰	δ^{13}C‰	δ^{15}N‰	δ^{13}C‰	δ^{15}N‰
Median	-14.9	8.9	-15.5	8.4	-15.3	8.3
IQR	1.5	0.4	0.7	0.5	0.8	0.8
Mean	-14.8	9.0	-15.6	8.4	-15.3	8.5
Standard deviation	1.1	0.3	0.5	0.4	0.8	0.5

Table 6.9. Median, mean, interquartile ranges and standard deviations of δ^{13}C and δ^{15}N values for the Dolge njive human dataset, separated by skeletal element sampled.

Figure 6.26 is a box and whisker plot of the δ^{13}C values of apex dentine, rib and long bone collagen. The interquartile ranges for these categories are between ~1 and ~2‰. Means and medians are generally comparable between the element types (see Table 6.9). The apex dentine category is skewed towards higher δ^{13}C values, whereas the long bone category shows a skew towards lower δ^{13}C values. Rib δ^{13}C values show a symmetrical spread. Overall, most of the isotope ratios can be found within the range of roughly -16‰ to -14‰. This suggests that the individuals buried at Dolge njive were consuming C4 plants throughout childhood and adulthood (Tykot 2004).

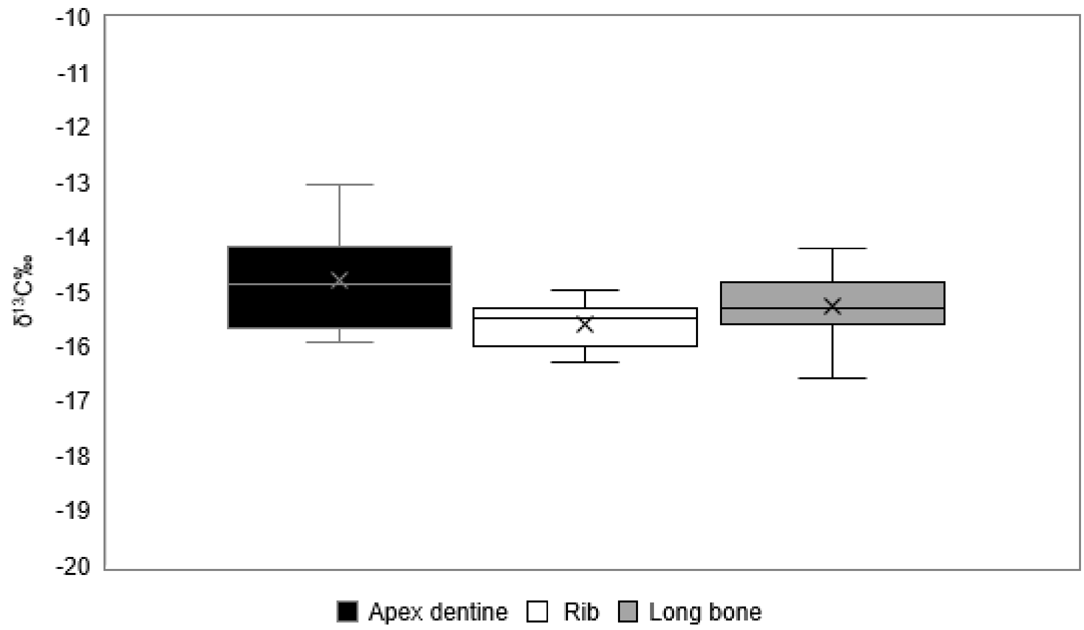

Figure 6.26. Box and whisker plot comparing δ^{13}C values from Dolge njive, divided by skeletal element Dentine (n=7); Rib (n=7); Long bone (n=6). *An isotopic variation of between c. 1.5‰ and c. 4‰ is observed within categories. The highest variation is observed in the apex dentine category*

Figure 6.27. Box and whisker plot comparing δ^{15}N values from Dolge njive divided by skeletal element Dentine (n=7); Rib (n=7); Long bone (n=6). *Minimal isotopic variation is observed between and within categories.*

When compared to the δ^{13}C values produced from the collagen of those buried at Dolge nijve, the δ^{15}N values exhibit smaller and more concise ranges (Figure 6.27). Means, medians and interquartile ranges are also very similar between the categories (Table 6.9). This suggests that there was very little change in the nitrogen isotopic composition of diet within the community or throughout life.

The carbon and nitrogen results of bone and dentine collagen sourced from the Dolge njive skeletons do not provide any evidence of dietary variation, and no outliers were identified. The small number of individuals uncovered at this site means that this is not a representative data set, but these results do agree with the interpretations made at the regional and inter-site scales.

Inter-individual isotopic variation

Similar to the Križna gora data, when the $\delta^{13}C$ and $\delta^{15}N$ values of different skeletal elements from a single individual are compared (Figures 28 and 29), there is little evidence to suggest any significant, isotopically detectable dietary change throughout the lifespan of most of the individuals buried at Dolge njive. The greatest variation in $\delta^{13}C$ values is was observed from the collagen of Grave 2680. In this case, there is a range of 3.3‰. This indicates a drop in the quantity of C4 plants consumed between childhood and adulthood (Tykot 2004). However, together, the $\delta^{13}C$ values from this individual are not unusual when compared to the rest of the cemetery group. This range in $\delta^{13}C$ values could simply be the result of personal choice or availability.

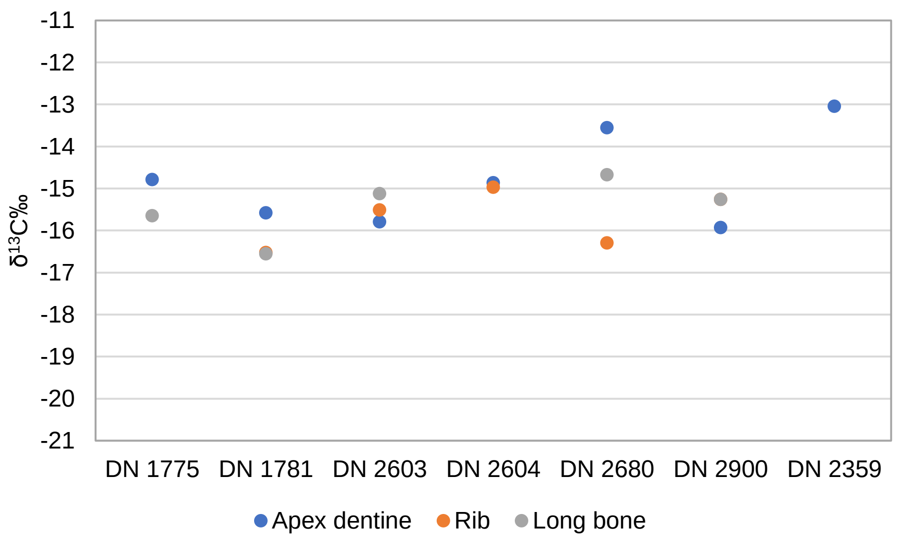

Figure 6.28 Comaprison of $\delta^{13}C$ values sampled from the same individual, Dolge njive. Dentine (n=7); Rib (n=7); Long bone (n=6).

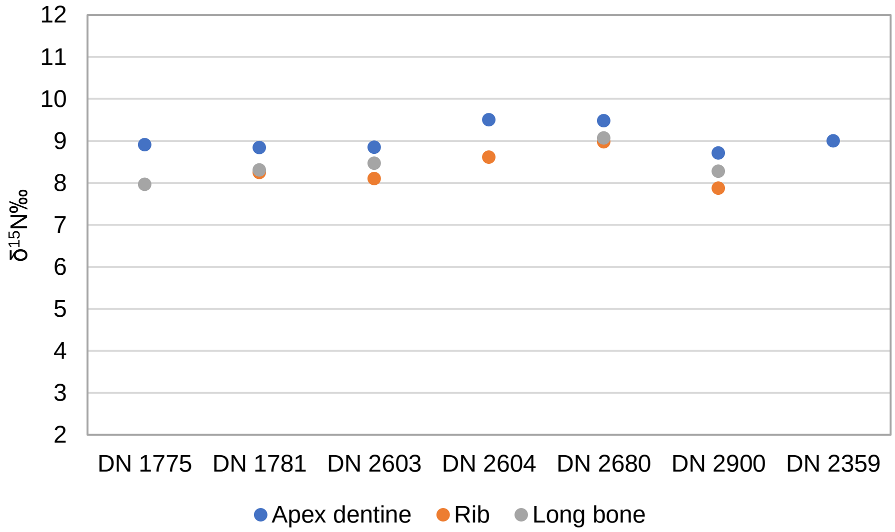

Figure 6.29 Comaprison of $\delta^{15}N$ values sampled from the same individual, Dolge njie. Dentine (n=7); Rib (n=7); Long bone (n=6).

The $\delta^{15}N$ values obtained from the different collagen sources from single individuals show less isotopic variation than the $\delta^{13}C$ values. Apex dentine samples are consistently higher, which is probably related to variable metabolic and dietary changeability during childhood, explained in more detail elsewhere in this thesis (Millard 2000; Fuller et al. 2006; Beaumont et al. 2015). Overall, individuals buried at Dolge njive appear to have been consuming a constant source of terrestrial protein throughout their life courses.

Obrežje

The results of isotope analysis on the bone and dentine collagen of individuals buried at Obrežje have produced the highest level of variability within a single site (Table 6.10 and Figures 6.30 and 6.31). This was surprising, given that this was also one of the smallest collections of remains from a single cemetery. Five individuals were available from this site. Four could be sampled for apex dentine, three for rib, and four for long bone collagen.

The $\delta^{13}C$ values from this cemetery are presented in Figure 6.30. The ranges here are far greater than that seen at either Dolge njive or Križna gora, especially from the apex dentine category. While the apex dentine and long bone samples are roughly symmetrical in their spread, it can be observed that the rib category shows a skew towards lower $\delta^{13}C$ values. This spread of values indicates that there is a variation in the amount of C4 carbon-based protein being consumed by those buried at this cemetery (Tykot 2004).

	Apex Dentine (n=5)		Rib (n=3)		Long bone (n=4)	
	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$
Median	3.4	1.6	1.4	0.5	1.1	0.5
IQR	1.4	0.5	3.4	1.6	1.1	0.5
Mean	-15.4	9.9	-15.0	9.4	-15.0	9.3
Standard deviation	2.2	0.8	1.5	0.3	0.9	0.3

Table 6.10. Median, mean, interquartile ranges and standard deviations of $\delta^{13}C$ and $\delta^{15}N$ values for the Obrežje human dataset.

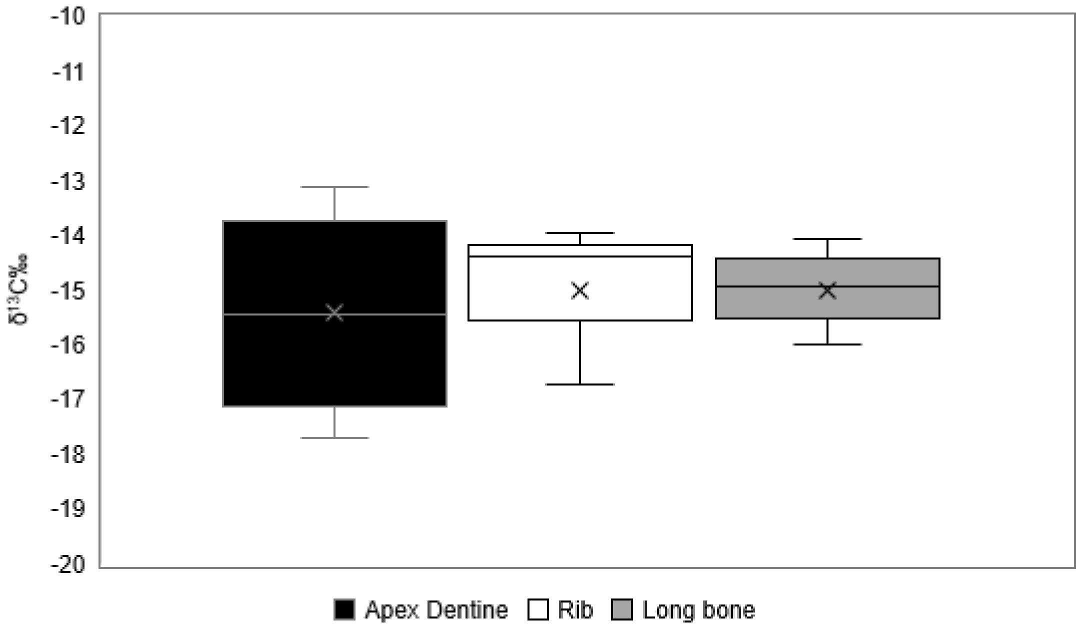

Figure 6.30. Box and whisker plot comparing $\delta^{13}C$ values from Obrežje, divided by skeletal element: Dentine (n=5); Rib (n=3); Long bone (n=4). There is a considerable isotopic variation of between 2‰ and 4‰ within each skeletal element category. The highest level of variation is observed in the apex dentine category

Figure 6.31. Box and whisker plot comparing δ^{15}N values from Obrežje, divided by skeletal element: Dentine (n=5); Rib (n=3); Long bone (n=4). Isotopic variation is minimal, but the variation is highest in the apex dentine category

The δ^{15}N values are much more constrained, with the apex dentine category once again providing the largest spread of values (Figure 6.30). This suggests that these individuals were consuming a similar quantity of terrestrial protein, of a similar type (Ambrose 1991; Richards 2003; Hedges and Reynard 2007).

The cause of this high degree of variation seen, primarily in the δ^{13}C values, is almost certainly due to the context of this cemetery site. This is not a culturally representative group of individuals. This is not only because of the small number of individuals recovered from this cemetery (although this is an important consideration) but also because of the unique use of this area as a funerary landscape.

<u>*Inter-individual isotopic variation*</u>

As has been discussed regarding the cemeteries of Križna gora and Dolge njive, Individuals buried at Obrežje show a similar level of isotopic variation (<2‰) between different collagen samples from a single individual. The same patterns observed from the former two cemeteries are also identified in this dataset (Figures 6.32 and 6.33). Apex dentine samples are typically higher for both δ^{13}C and δ^{15}N values. The only exception for this trend can be observed in the Long bone and Apex dentine samples obtained from Grave 3043. Here, the Long bone collagen sample has a $\delta^{13}C$ value almost c.1.5‰ higher than this Apex dentine collagen sample. This indicates an increase in C4 plant consumption between childhood and adulthood, whereas the individuals buried in Graves 2544 and 12664 (a non-adult), show a potential decrease in C4 plant consumption (Tykot 2004). However, these apparent differences in $\delta^{13}C$ values are small, and probably reflective of personal choice or seasonal availability, rather than a conscious change in dietary practices. The isotopically detectable variation in $\delta^{15}N$ values is very slight, suggesting a similar source of terrestrial protein was consumed throughout the life of these people.

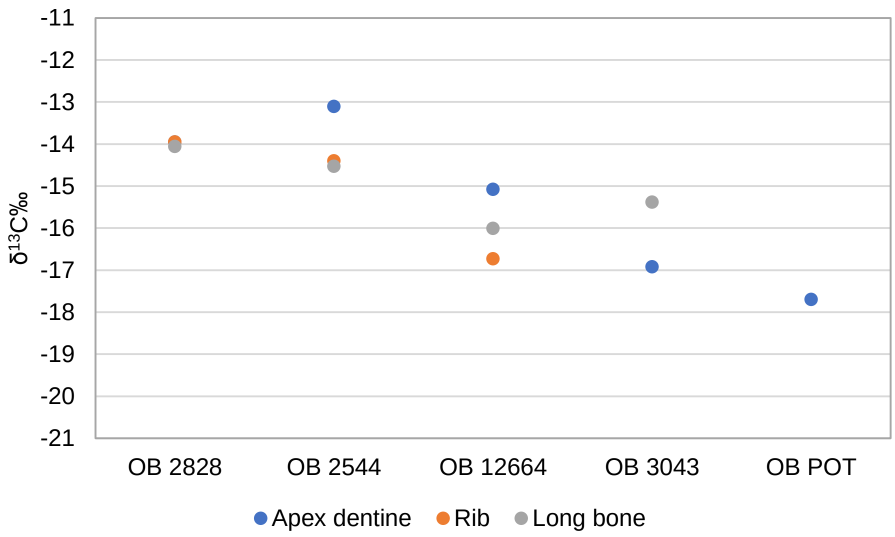

Figure 6.32 : Comaprison of $\delta^{13}C$ values sampled from the same individual, Obrežje Dentine (n=5); Rib (n=3); Long bone (n=4).

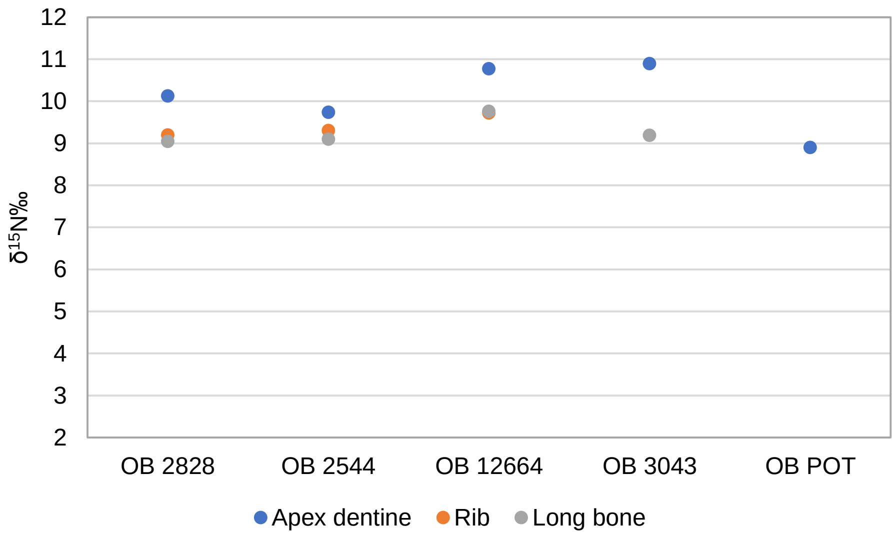

Figure 6.33 : Comaprison of $\delta^{15}N$ values sampled from the same individual, Obrežje. Dentine (n=5); Rib (n=3); Long bone (n=4).

This case study provides a clear example of where isotopic variability can be interpreted in multiple ways, and how the context and knowledge of a cemetery are imperative. The problematic nature of this cemetery site is discussed later in this chapter and elsewhere in the thesis.

6.2.6 Overview of bulk carbon and nitrogen isotope analyses

- $\delta^{13}C$ and $\delta^{15}N$ values from bulk collagen samples have provided evidence of a temporally and spatially widespread, homogenous diet based on terrestrial animal protein and a mix of C3 and C4 plants
- C4 plants, probably millet, played a significant role in the diet of the people inhabiting this study area
- The sampling of multiple skeletal elements has shown that the isotopic composition of diet remained largely homogenous throughout life
- The high level of isotopic homogeneity observed at regional and site-based scales indicates that there were no differences in the isotopic composition of diet based on age, sex or social structure
- There was an increased variability in the dentine collagen samples relative to rib and long bone samples
- Abrupt or seasonal changes in the isotopic composition of diet were probably masked by differential rates of bone turnover, with the actively forming dentine recording isotopic variation at a higher resolution

6.3 Incremental dentine analysis

Based on the analysis of individuals radiocarbon dated to the Middle Bronze Age to the Iron Age, there is evidence for homogeneity and continuity in diet, following the application of carbon and nitrogen isotope analysis on bulk collagen samples. To test the validity of some of the interpretations made from the results of this method, a higher resolution technique was adopted to explore any potential, more subtle variations in $\delta^{13}C$ and $\delta^{15}N$ values. For this, incremental dentine analysis was chosen, as this method provides a high-resolution snapshot of childhood diet (Beaumont et al. 2013b; Beaumont et al.

2015). As seen in the results from bulk collagen analysis, although there is a relatively higher level of variation seen in the apex dentine samples than rib or long bone samples, $\delta^{13}C$ and $\delta^{15}N$ values from all element types were generally similar. This suggested that there was little dietary variability between life stages.

A key consideration with the sample chosen for this sampling method is that only non-adults were selected. Time and financial constraints made a larger sample, including individuals who had survived into adulthood, impossible. Instead, it was decided to investigate dietary and metabolic change in individuals who did not survive into adulthood to explore themes of childhood health and mortality. The individuals and the teeth sampled are given in Table 3.6.

The results of incremental dentine analysis for $\delta^{13}C$ and $\delta^{15}N$ values can be found in this section as well as Appendix E, Disk 1. As presented in Tables 6.11 and 6.12 and Figures 6.34 to 6.44, isotopic profiles from multiple tooth types, time periods and cemetery sites have been produced. These profiles reveal a high level of variation of $\delta^{13}C$ and $\delta^{15}N$ values throughout the development of these teeth. The common occurrence of co-varying $\delta^{13}C$ and $\delta^{15}N$ values indicate that these changes in isotopic ratios were probably more frequently caused by a change in the isotopic composition of diet, than metabolic influences (Beaumont et al. 2013a; Beaumont and Montgomery 2016).

6.3.1 Presentation of incremental dentine results

The following section provides a broad overview and initial interpretations of the incremental dentine analysis. After this, individual carbon and nitrogen isotope profiles shall be addressed in more detail, as will trends observed in paired deciduous and permanent teeth. Deciduous teeth will also be addressed in isolation, as these samples are more complex to interpret because of the timing of their development, as their initial increments may have been affected by their mother's isotopic pool, having formed *in utero* (Beaumont et al. 2015).

Whole tooth means	*$\delta^{13}C$‰*	*$\delta^{15}N$‰*
Križna gora 75 deciduous first molar	-13.9	12.2
Križna gora 75 permanent first molar	-14.2	11.3
Križna gora 59 permanent second premolar	-16.7	9.4
Zagorje Infant 1 deciduous first incisor	-12.1	12.0
Obrežje 12664 deciduous first molar	-14.6	11.7
Obrežje 12664 permanent first molar	-15.1	10.8
Sv Križ 4 deciduous first molar	-15.5	11.1
Sv Križ 4 permanent first molar	-15.9	11.2
Sv Križ Horseman permanent first molar	-15.2	9.4
Ljubljana Congress Square 1029A permanent first molar	-14.1	8.3
MEAN‰	*-14.6*	*10.7*
Stdev‰	*1.3*	*1.4*

Table 6.11. The whole tooth means ($\delta^{13}C$ and $\delta^{15}N$) calculated from all dentine increments and standard deviation and mean values for all dentine increments from all teeth.

Ranges	Lowest $\delta^{15}N$‰	Highest $\delta^{15}N$‰	*Difference (‰)*	Lowest $\delta^{13}C$‰	Highest $\delta^{13}C$‰	*Difference (‰)*
Križna gora 75 deciduous first molar	10.3	13.3	*3.0*	-15.8	-13.0	*2.8*
Križna gora permanent first molar	9.7	13.4	*3.7*	-16.3	-12.6	*3.7*
Križna gora permanent second pre-molar	9.1	9.6	*0.5*	-17.5	-16.2	*1.3*
Zagorje Infant 1 deciduous first molar	11.2	13.5	*2.3*	-12.6	-11.3	*1.3*
Obrežje 12664 deciduous first molar	11.0	13.5	*2.5*	-16.7	-13.6	*3.1*
Obrežje 12664 permanent first molar	9.6	13.2	*3.6*	-17.7	-13.1	*4.6*
Sv Križ 4 deciduous first molar	10.5	12.5	*2.0*	-16.5	-14.8	*1.7*
Sv Križ 4 permanent first molar	9.9	12.9	*3.0*	-17.0	-15.5	*1.5*
Sv Križ Horseman permanent first molar	8.4	12.1	*3.7*	-16.1	-13.8	*2.3*
Ljubljana Congress Square 1029A permanent first molar	7.9	9.7	*1.8*	-15.4	-13.2	*2.2*

Table 6.12. Maximum and minimum $\delta^{13}C$ and $\delta^{15}N$ values and Intra-tooth ranges of $\delta^{13}C$ and $\delta^{15}N$ values calculated from of dentine increments.

6.3.2 Carbon isotope ratios

In many of these isotopic profiles, abrupt swings in $\delta^{13}C$ values of up to ~2‰ can be identified. Repetitive cycles of higher and lower $\delta^{13}C$ values suggest a shift in focus between the use of C3 and C4 plant-based proteins (Tykot 2004). This is evidence to suggest that, although still an important crop, millet was not necessarily always the dominant grain. Alternatively, $\delta^{13}C$ values are consistently higher in the earlier increments of both deciduous and permanent teeth. This could suggest a shifting focus between C4 and C3 based proteins during early childhood, a time when diet is expected to modify through episodes of breastfeeding, weaning and normalisation to that of the adult population (Millard 2000; Fuller et al. 2006; Jay et al. 2008; Beaumont et al. 2015). This period of life would influence isotope ratios, not only because the foodstuffs themselves are being altered, but also because the source and routing of macronutrients also change as more food groups are included into the overall diet (Wright and Schwarcz 1998). A key example of this would be the onset of weaning, whereby solid foods are introduced, and the child is no longer obtaining all their macronutrients from the mother's milk (Wright and Schwarcz 1998). The transition from a diet high in lipids to one inclusive of a higher quantity of plants and other foodstuffs could influence the $\delta^{13}C$ values produced from dentine sections (Wright and Schwarcz 1998).

6.3.3 Nitrogen isotope ratios

Except for Ljubljana Congress Square 1029 A and Križna gora 59, all the initial dentine increments of isotope profiles exhibit relatively high $\delta^{15}N$ values, commonly ~2‰ to ~3‰ above that of their final increment. This trend is most notable in isotope profiles produced from deciduous teeth, where $\delta^{15}N$ values rise sharply around the time of birth and then fall steadily throughout the development of the tooth. This abrupt rise and subsequent fall in values could indicate metabolic stress around the time of birth, followed by a period of stabilisation and recovery (Fuller et al. 2005; Mekota et al. 2009; Beaumont et al. 2015; Reynard and Tuross 2015). Alternatively, the rise in $\delta^{15}N$ values could be related to the onset of breastfeeding, with the fall in $\delta^{15}N$ values indicative of the onset of weaning (Millard 2000; Fuller et al. 2006). However, as $\delta^{15}N$ values are seen to start decreasing relatively early in the development of the teeth (e.g. Obrežje 12664 $\delta^{15}N$ values begin to fall at c.0.2 years and Križna gora 75 deciduous c.0.4 years) this would be very early for the initiation of weaning. However, it is important to note that each increment has been attributed with an approximate age that is likely affected by averaging effects and a lag in the incorporation of isotope signals (Beaumont et al. 2013b).

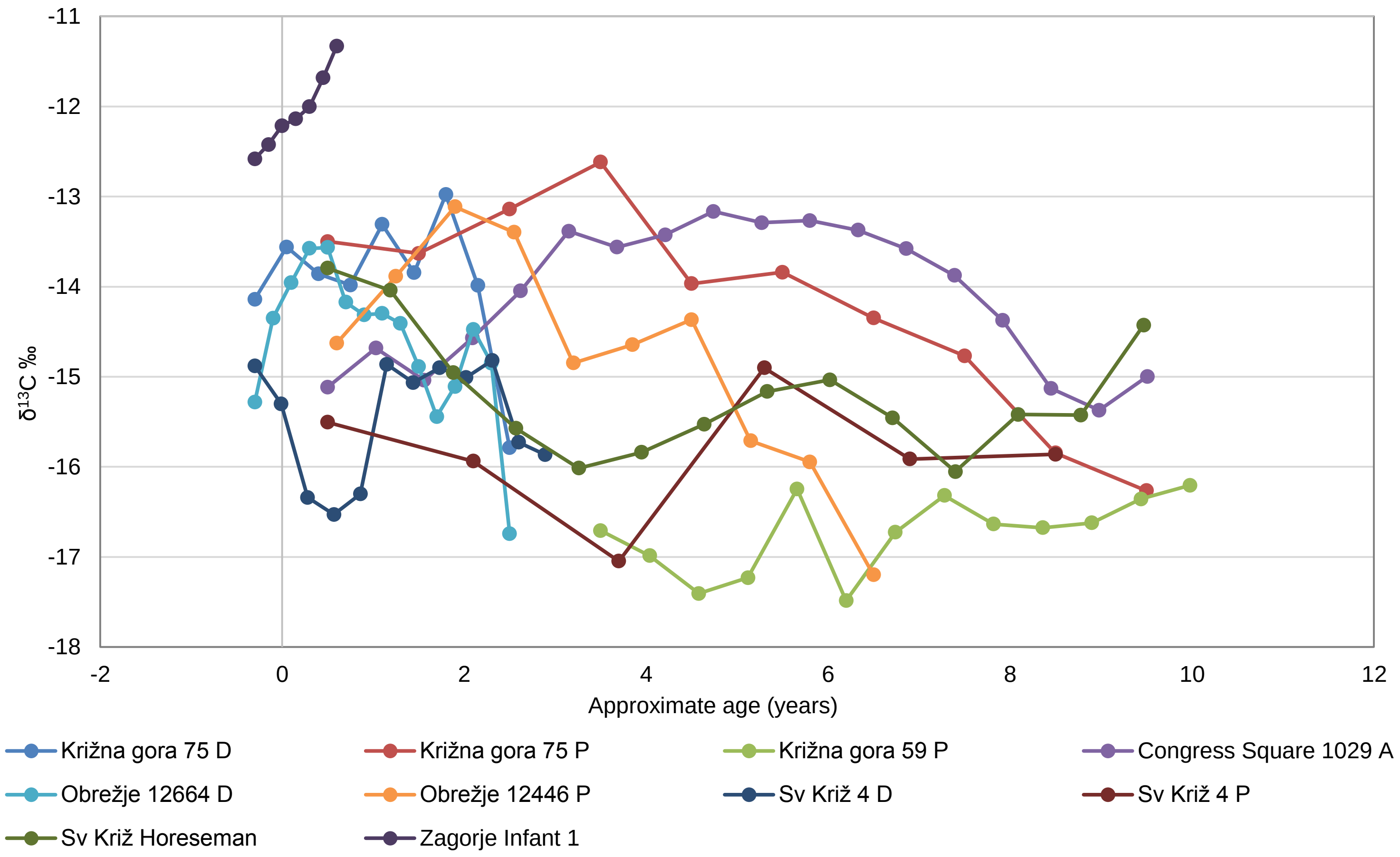

Figure 6.34. A plot of $\delta^{13}C$ profiles generated from all individuals sampled for incremental dentine analysis. Increments have been associated with an approximate age to compare isotopic variability across similar periods of dentine development. This plot includes both deciduous (D) and permanent (P) teeth. These have been indicated where more than one tooth was sampled from the same individual. All carbon isotope profiles show a high level of variability, indicating frequent shifts in diet (more or less C4). The profile from Zagorje ob Savi, Infant 1, is significantly different from the remaining profiles, with notably higher $\delta^{13}C$ values

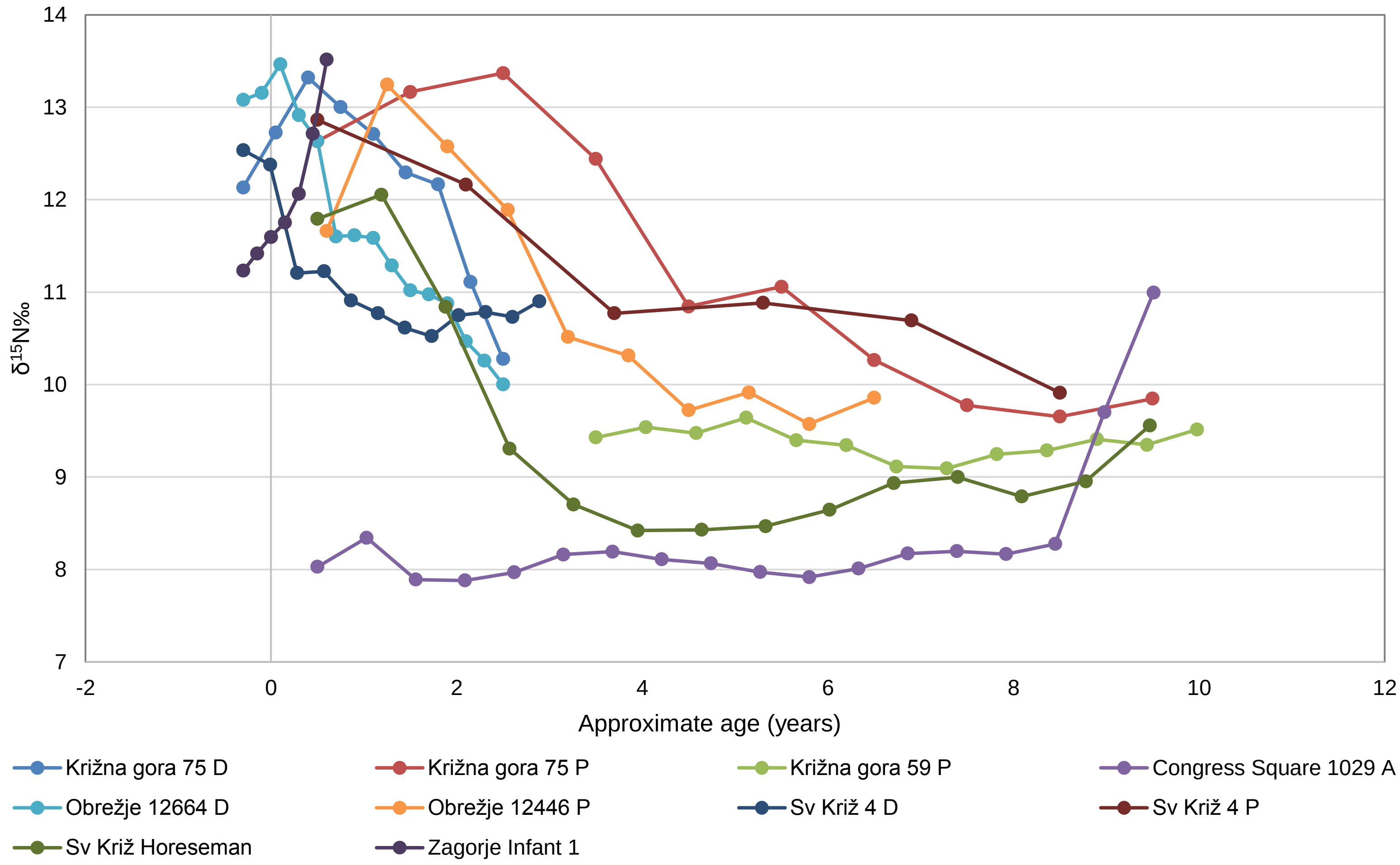

Figure 6.35. A plot of $\delta^{15}N$ profiles generated from all individuals sampled for incremental dentine analysis. Increments have been associated with an approximate age to compare isotopic variability across similar periods of dentine development. This plot includes both deciduous (D) and permanent (P) teeth. These have been indicated where more than one tooth was sampled from the same individual. Except for Congress Square 1029 A and Zagorje ob Savi Infant 1, all isotope profiles exhibit similar, highly variable trends.

6.3.4 Incremental dentine: individual isotope profiles

Ljubljana Congress Square 1029A: permanent first molar

The permanent first molar belonging to the child aged c.10 years of age and buried at Ljubljana Congress Square displays a different trend in their carbon and nitrogen isotope ratios in comparison to the other individuals sampled for this analysis. Firstly, this individual has produced comparatively low $\delta^{15}N$ values with a range of 7.9‰ to 10.9‰. As shown in Figure 6.36, most increments reflect relatively stable $\delta^{15}N$ values at ~8‰, with the higher $\delta^{15}N$ values occurring at the end of the profile. While the $\delta^{15}N$ values are relatively stable, the $\delta^{13}C$ values exhibit a swing from lower to higher $\delta^{13}C$ values, reflecting an increased consumption of C4 plants, followed by a drop of a similar magnitude (Beaumont et al. 2013a; Beaumont et al. 2013b; Beaumont and Montgomery 2016). The largest changes in $\delta^{15}N$ values are associated with a similar shift in the $\delta^{13}C$ values, with increasing $\delta^{15}N$ values towards the apex of the root, co-varying with a decrease in $\delta^{13}C$ values of ~2‰ beginning around the age of 7 years, indicating a reduction in C4 consumption (Beaumont et al. 2013a; Beaumont et al. 2013b; Beaumont and Montgomery 2016). Although there was no evidence of pathological lesions on the skeleton, the sudden increase in $\delta^{15}N$ values of ~3‰ in the final three increments of 1029 A's profile is indicative of metabolic stress, which may have been connected to the death of this child (Fuller et al. 2005; Kinaston et al. 2009; Beaumont et al. 2015).

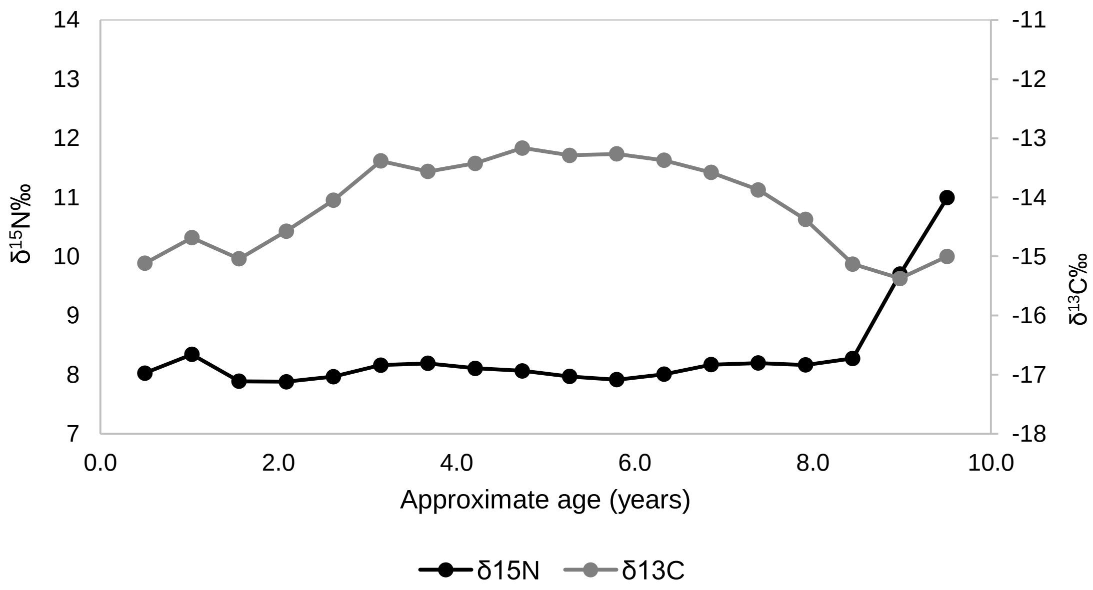

Figure 6.36. An incremental dentine profile of $\delta^{13}C$ and $\delta^{15}N$ values for Ljubljana Congress Square 1029 A (permanent first molar). A large swing in $\delta^{13}C$ values can be observed throughout the development of the tooth root, while $\delta^{15}N$ values remain constant until rising abruptly at the end of the profile. This individual died c.9.5 years of age. The sudden increase in $\delta^{15}N$ values could be related to a negative nitrogen balance or metabolic condition

Zagorje ob Savi Infant 1: deciduous first incisor

The $\delta^{15}N$ values recorded in the dentine increments from Infant 1 from Zagorje ob Savi are similar to the initial increments of other deciduous and permanent teeth, however, their trajectory and velocity of increase are distinctive relative to other individuals. As shown in Figures 6.37, but more obviously in Figure 6.35, $\delta^{15}N$ values increase sharply from the outset at a gradient greater than other profiles covering the same period of development.

This infant is also distinctive in their $\delta^{13}C$ values. As can be observed in Figures 34 and 37, and Section 6.3.5, the $\delta^{13}C$ values are significantly higher than any other isotopic profile covering the same developmental period. The combination of anomalous $\delta^{13}C$ values and the trajectory of increasing $\delta^{15}N$ values suggest that this infant may have been consuming a diet unlike that of other children during the same developmental period.

This case must be viewed in context. Unlike the other children selected for incremental dentine analysis, this infant is known to have suffered from severe, chronic, metabolic disease. As such, this individual has been selected as a key case study, highlighting the importance of multi-disciplinary approaches to individual biographies (Chapter 7).

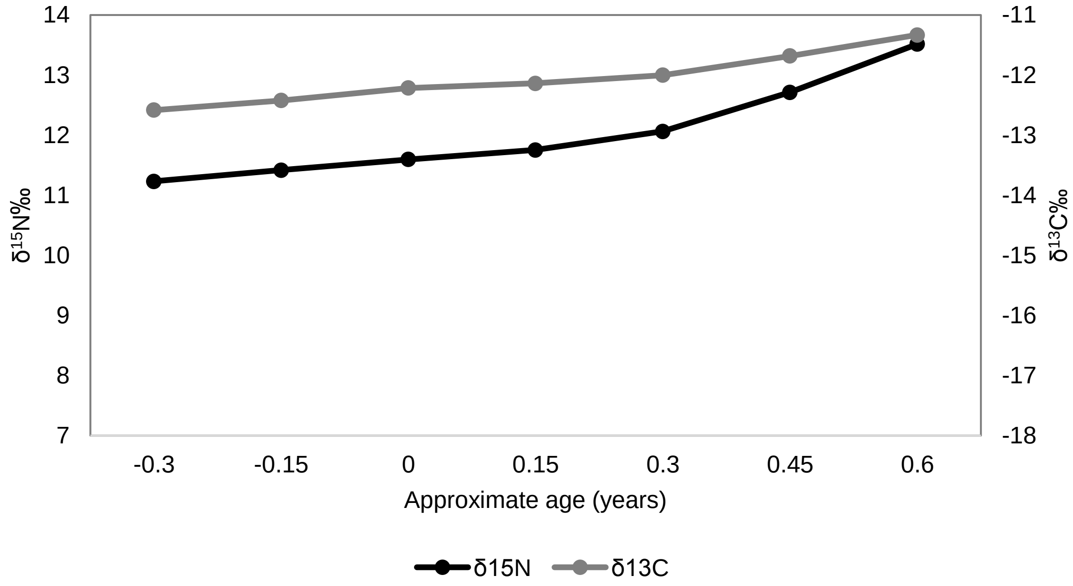

Figure 6.37. An incremental dentine profile of $\delta^{13}C$ and $\delta^{15}N$ values for Zagorje ob Savi Infant 1 (deciduous first incisor). Both $\delta^{13}C$ and $\delta^{15}N$ values continue to rise steadily throughout the development of the tooth root. This Infant died at approximately 7.5 months and so this isotope profile covers a very short time span. Isotope ratios have probably been influenced by in-utero isotope ratios, possibly reflecting the diet and metabolic condition of the mother during pregnancy.

Sv Križ, Horseman: first permanent molar

The Horseman buried at Sv Križ, Croatia, was the only individual included in the incremental dentine sampling that survived into adulthood. As depicted in the isotopic profile of their first permanent molar in Figure 6.38, similar shifts in both the carbon and nitrogen isotope ratios can be observed in comparison to the isotope profiles produced by the individuals who died during childhood.

Nitrogen isotope ratios are observed to start relatively high at 11.8‰ and drop by 2.1‰ between the initial increment and roughly three years of age. A similar trend is seen in the $\delta^{13}C$ values, starting at -13.8‰ and falling by 2.2‰ over the same period of development. The co-variance between $\delta^{15}N$ and $\delta^{13}C$ values indicates that these shifts in isotope ratios were caused by a change in a protein source, rather than by any metabolic influence (Beaumont and Montgomery 2016).

Fluctuations of ~+/-1‰ in both isotope ratios are observed throughout the development of the tooth. These shifts are arguably less extreme in comparison to profiles produced by other individuals, such as Ljubljana Congress Square 1029A, however, these small fluctuations do suggest that diet was not as homogeneous as the isotope values obtained from the bulk collagen samples previously indicated.

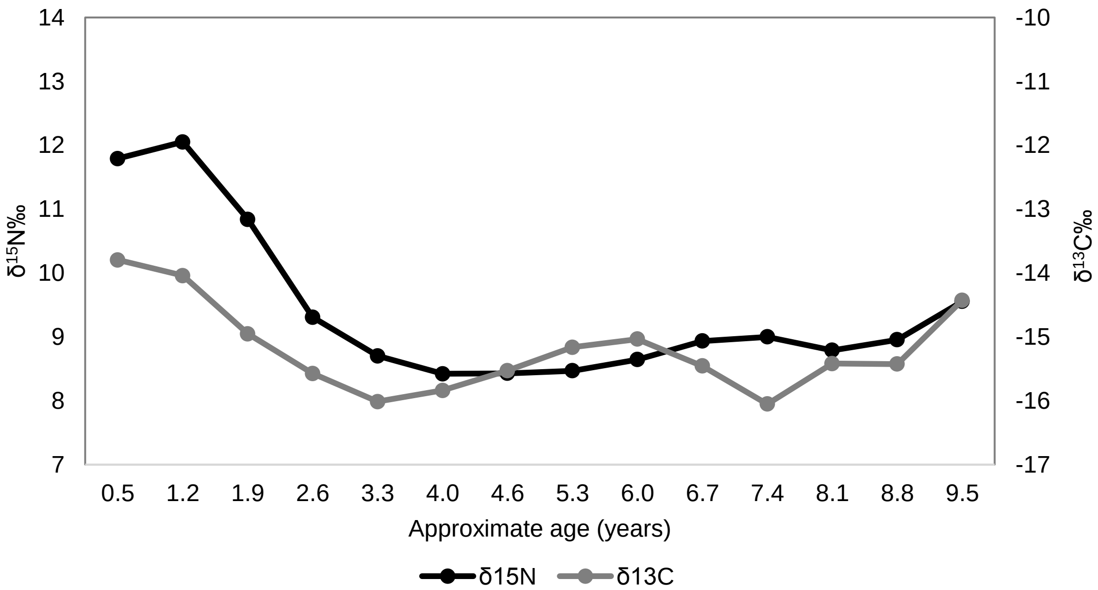

Figure 6.38. A $\delta^{13}C$ and $\delta^{15}N$ incremental dentine profile of a first permanent molar, Sv Križ Horseman. Both the $\delta^{13}C$ and $\delta^{15}N$ values are highest at the beginning of the profile, before dropping simultaneously. Small variations in both isotope ratios can be observed throughout the development of the tooth root.

6.3.5 Deciduous and permanent teeth

<u>Deciduous teeth: first year of development</u>

The high $\delta^{15}N$ values exhibited in most of the initial dentine increments of deciduous teeth is probably linked to the diet or metabolic condition of the mother, as these increments would have formed prior to birth in equilibrium with the mother's isotopic pool (Beaumont et al. 2015). When compared to an adult mean of $\delta^{15}N$ values calculated from adult rib collagen (a bone with a relatively short turnover period, and therefore a proxy for the isotopic composition of adult diet), of 8.6‰ +/- 0.6‰ the initial dentine increment from these deciduous teeth is +2.3‰ to +4.1‰ above. This could either indicate that the mothers of these children were consuming a diet different to that of the rest of the adult population whilst pregnant, or that they were suffering from metabolic stress (Beaumont et al. 2015). When the adult rib mean $\delta^{13}C$ value (15.5‰ +/- 0.8‰) is compared to the same dentine increments, there is a difference of between +0.2‰ and +2.9‰. This differential variation in $\delta^{13}C$ and $\delta^{15}N$ values is evidence to suggest that the differences in $\delta^{15}N$ values between the adult mean and the initial increments of deciduous teeth are related to metabolic stress during pregnancy, rather than a dietary change (Beaumont et al. 2015). This phenomenon has been reported by Fuller and colleagues (Fuller et al. 2004; Fuller et al. 2005) who found that the $\delta^{15}N$ values of women varied throughout pregnancy and women who, for example, suffered from morning sickness, tended to display a rise in $\delta^{15}N$ values during pregnancy. This rise in $\delta^{15}N$ values could be being reflected in the dentine of the children sampled as part of this study.

The first year of life is where shifts related to breastfeeding are theoretically more likely to be observed, with $\delta^{15}N$ values hypothetically increasing abruptly as the infant begins to ingest breast milk (Millard 2000; Fuller et al. 2006; Jay et al. 2008). As can be observed in Figures 6.39 and 6.40, ranges of ~2‰ are common in the first year of tooth development. $\delta^{15}N$ values are seen to increase in the profiles of Obrežje 12664 and Križna gora 75, but subsequently (except for Zagorje ob Savi Infant 1) begin to decrease after the first couple of months of life. This trend could be reflecting a recovery phase, following a period of metabolic stress or a breastfeeding signal (Millard 2000; Fuller et al. 2006; Beaumont et al. 2015).

Figures 6.41 and 6.42 further display the disparity between the carbon and nitrogen ratios produced by Zagorje ob Savi Infant 1 and the other individuals.

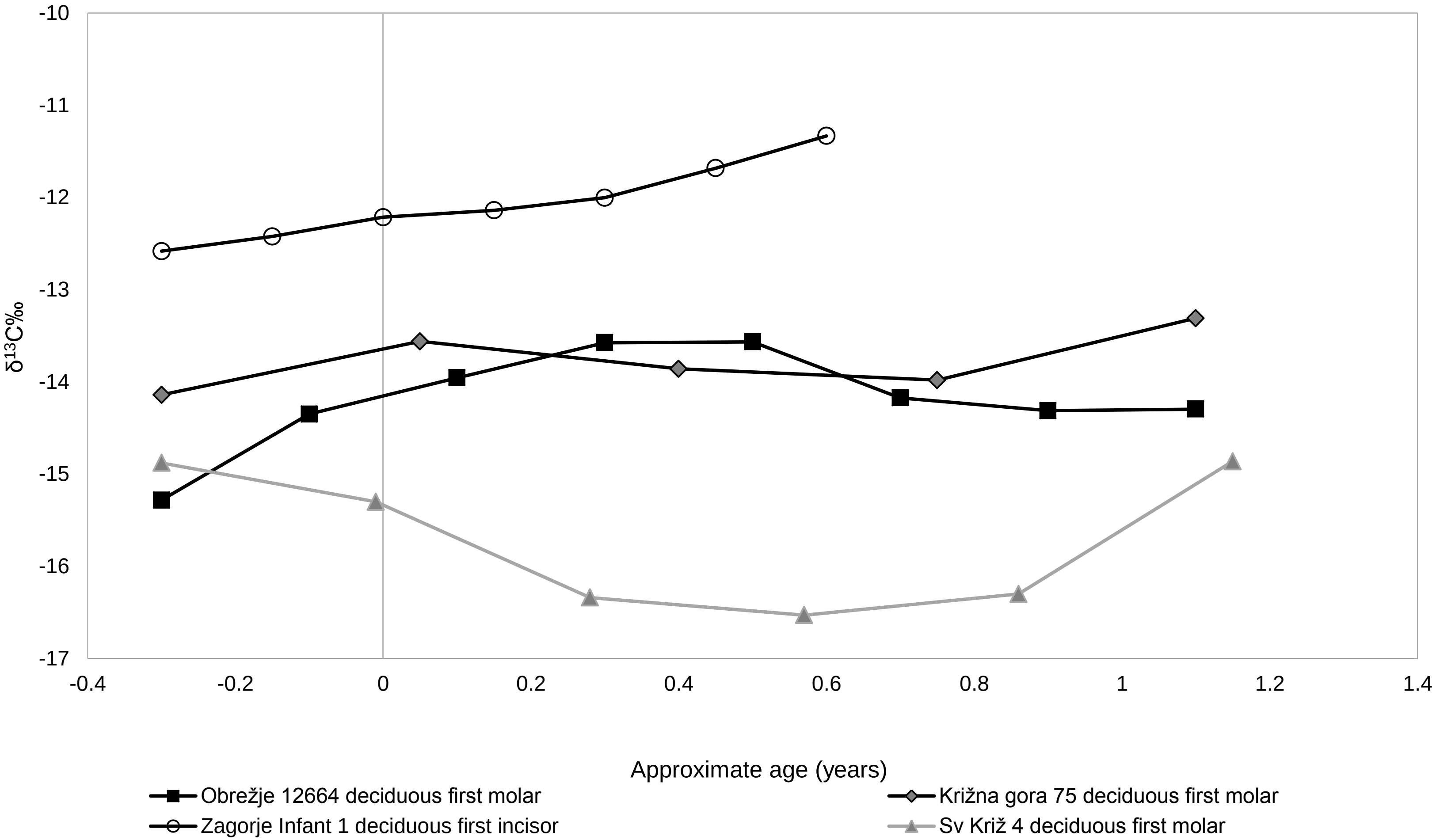

Figure 6.39. Incremental dentine profiles of $\delta^{13}C$ values for deciduous teeth, representing roughly the first year of life, except for Infant 1 from Zagorje ob Savi. For this individual, the full profile from pre-birth to death is presented. $\delta^{13}C$ values from this profile are noticeably higher than that of the other deciduous teeth, over the same period of development. The trajectory of Infant 1's profile is also different, as $\delta^{13}C$ values continue to increase, whereas other profiles show trends of increases and decreases

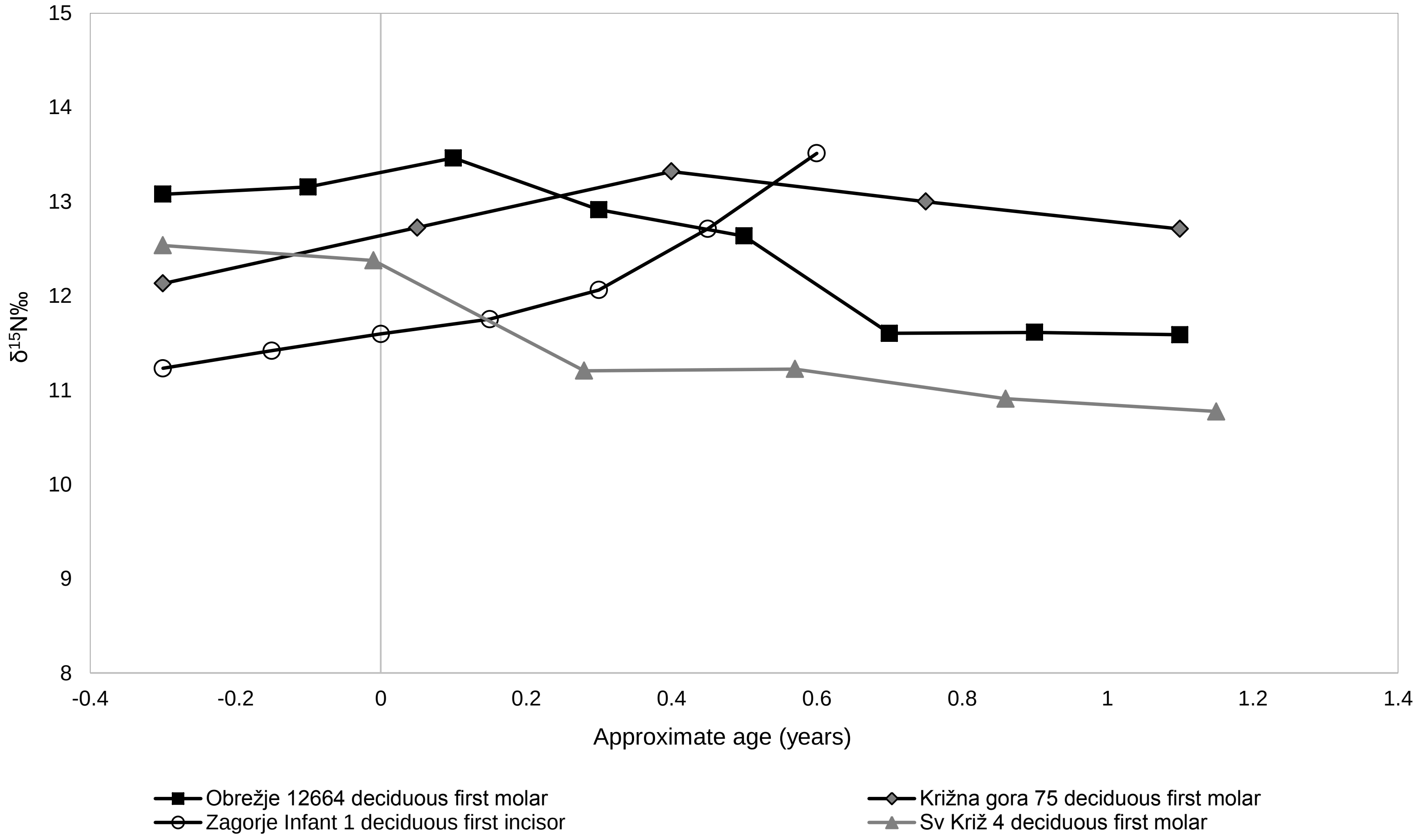

Figure 6.40. Incremental dentine profiles of $\delta^{15}N$ values from deciduous teeth, representing roughly the first year of life, except for Infant 1 from Zagorje ob Savi Infant 1. For this individual, the full profile from pre-birth to death is presented. Although the $\delta^{15}N$ values from this profile are the lowest for most of its increments, the rate of increase and trajectory follow a different trend to the other deciduous teeth. The $\delta^{15}N$ values of the other deciduous teeth begin higher and then drop, plateaux, or decrease, while the $\delta^{15}N$ values from Infant 1 continue to increase rapidly until death

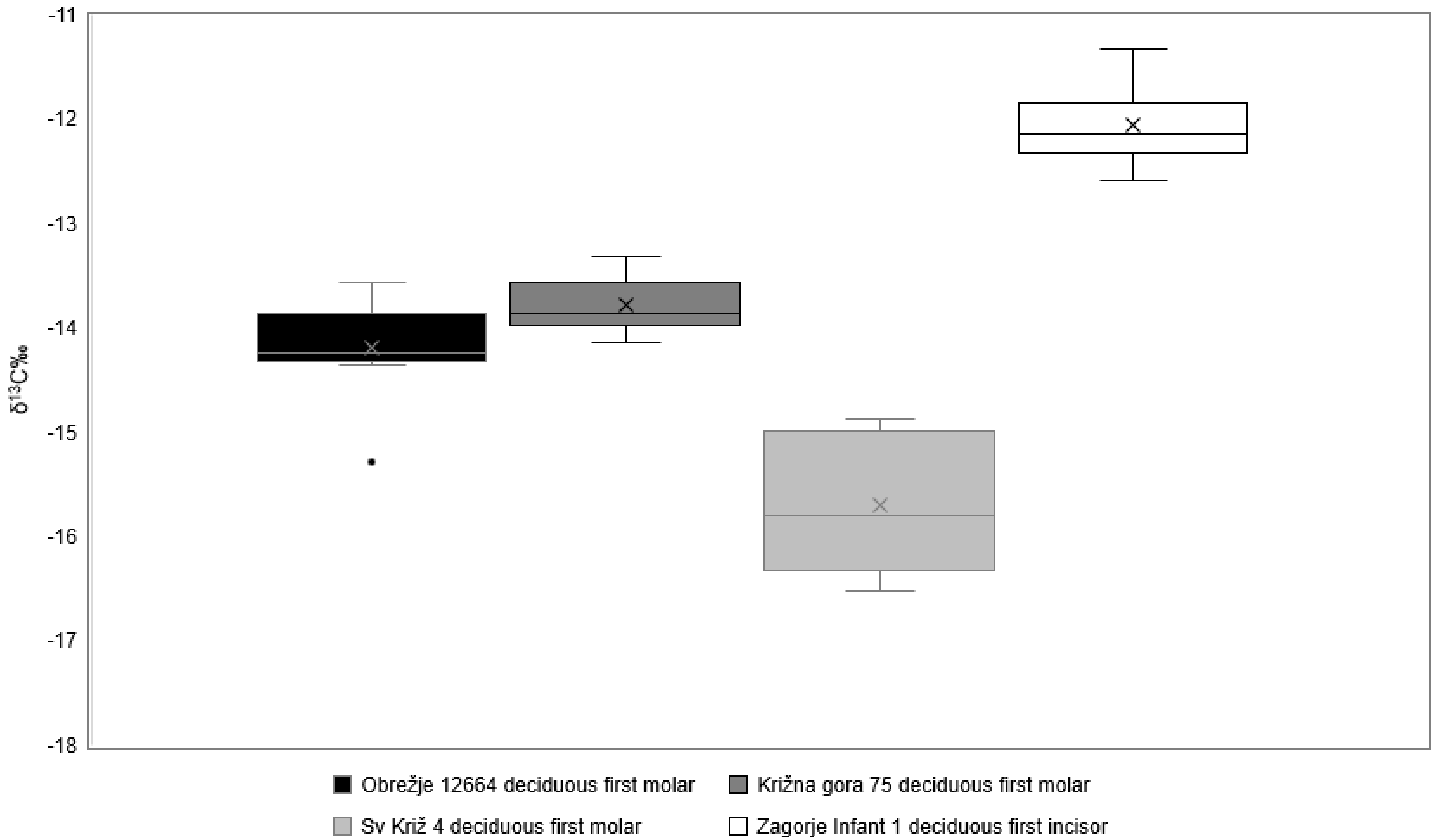

Figure 6.41. Box and whisker plot comparing $\delta^{13}C$ values for the first year of dental development of deciduous teeth, including pre-birth values. Significantly different trends in isotopic variation can be observed between the spreads of data from each deciduous tooth.

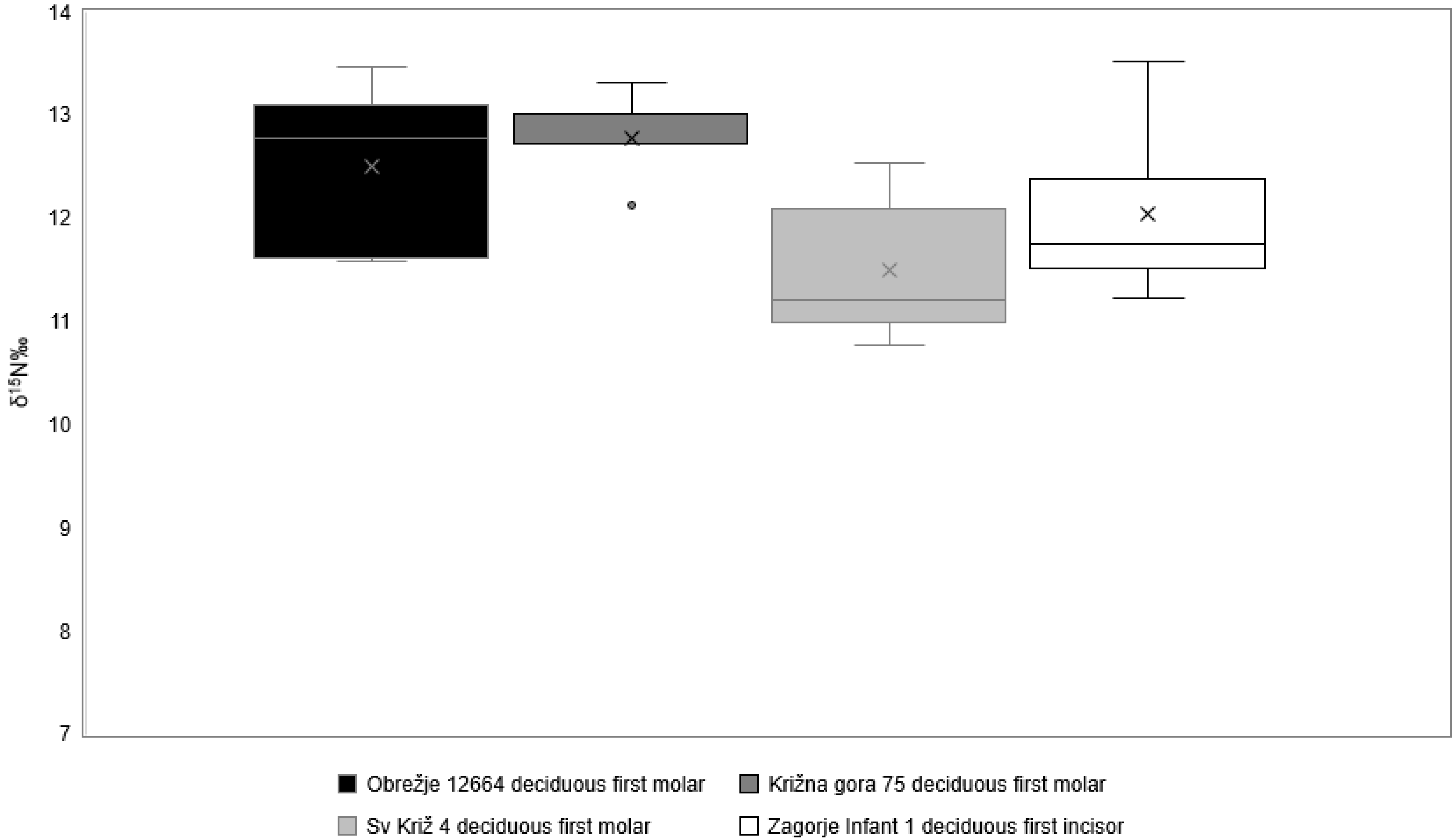

Figure 6.42. Box and whisker plot comparing $\delta^{15}N$ values for the first year of dental development of deciduous teeth, including pre-birth values. With the exception of Križna gora 75, $\delta^{15}N$ values are observed to vary by c.2‰ over this period

Combined deciduous and permanent teeth

It was possible to combine carbon and nitrogen isotope profiles of deciduous and permanent teeth from the same individual for Križna gora 75 (Figure 6.43) and Obrežje 12664 (Figure 6.44), and Sv Križ 4 (Figure 6.45), though the context between the teeth from this latter site is less certain because of the co-mingled nature of the remains excavated from this site.

A discrepancy in $\delta^{13}C$ and $\delta^{15}N$ values can be observed where isotope ratios are expected to overlap between deciduous and permanent teeth. At c.0.5 years of age, there is a difference of 0.4‰ in the $\delta^{13}C$ values and a 0.7‰ difference in the $\delta^{15}N$ values between the deciduous and permanent dentine of Križna gora 75. Similarly, there is a 1‰ difference in the $\delta^{13}C$ values and a 2.9‰ difference in $\delta^{15}N$ values at the same rough age between permanent and deciduous teeth from Obrežje 12664. This could be explained as a lag in the incorporation of isotopes into dental tissues (Beaumont et al. 2013b). The approximate ages attributed to increments represents a midpoint of tooth development of +/- 0.5 years (AlQahtani 2010; Beaumont et al. 2013b; Beaumont et al. 2015). Also, the sampling method is not 100% precise, as increments are taken horizontally, while the dentine is known to develop diagonally (Hillson 1996: 182-190). For this reason, although this is a high-resolution method, isotope ratios do not exactly equate to biological age and averaging effects need to be considered (Beaumont et al. 2013b). The ages attributed to individual increments are, instead, used as a rough guide to relate isotopic change to developmental stages. For this reason and given the significant amount of variation recorded in the dentine of these individuals, it is not unusual that the isotopic profiles of deciduous and permanent teeth do not line up exactly.

The trajectory of the isotope profiles between deciduous and permanent teeth show strong similarities, with both $\delta^{13}C$ and $\delta^{15}N$ values starting high and then falling throughout the development of both teeth. This supports the interpretation that there was a high level of isotopic variation throughout early childhood and into late childhood. The co-varying $\delta^{13}C$ and $\delta^{15}N$ values visible in the profiles of both deciduous and permanent teeth also support the theory that these shifts in isotope ratios were caused by dietary, rather than metabolic change (Beaumont et al. 2013a; Beaumont et al. 2013b; Beaumont et al. 2015; Beaumont and Montgomery 2016).

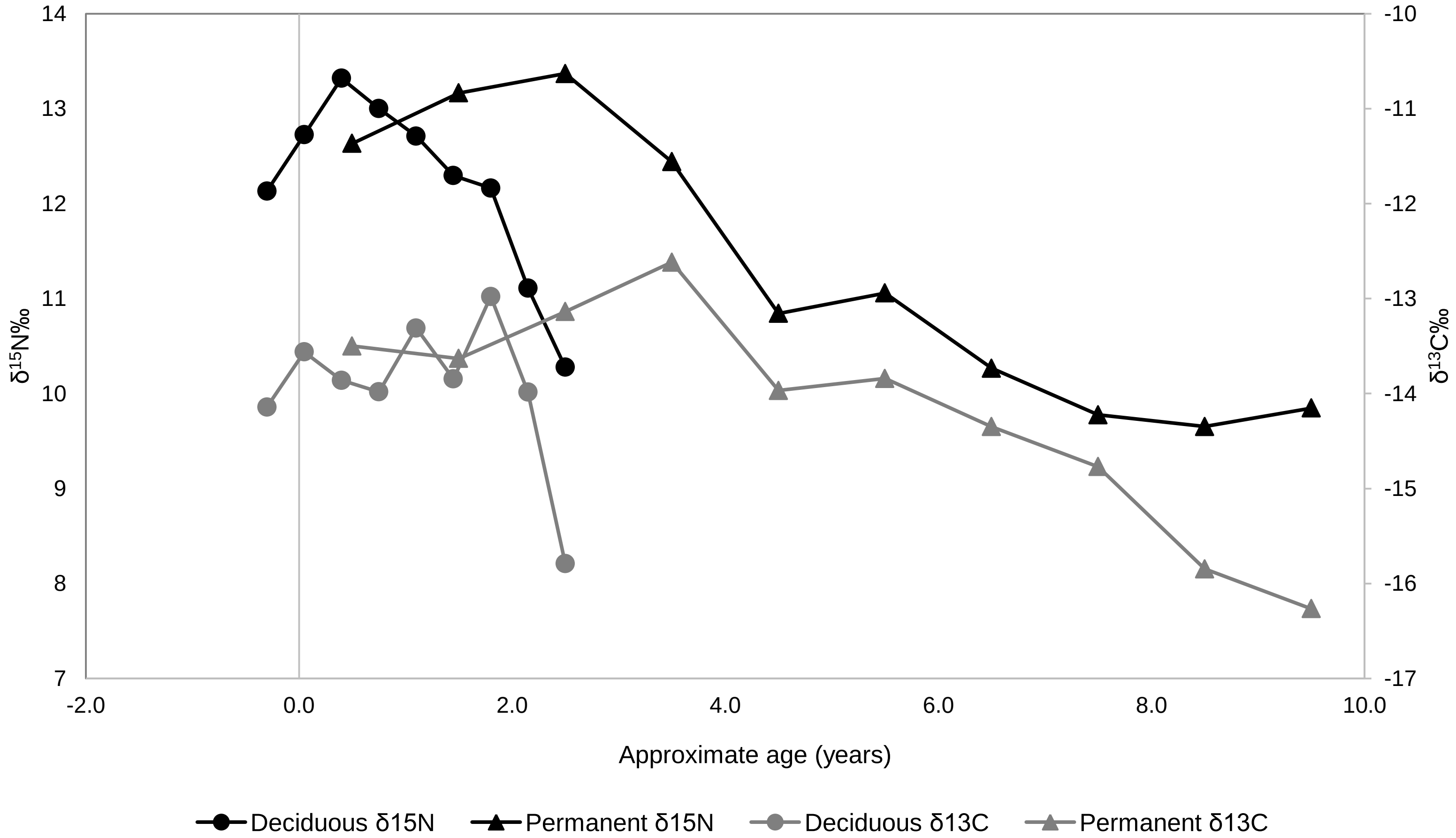

Figure 6.43. A plot of $\delta^{13}C$ and $\delta^{15}N$ incremental dentine profiles, of deciduous and permanent first molars, Križna gora Grave 75. The apex of the permanent tooth was complete, but this individual died at c.9.5 years and so the final increments would reflect the isotopic composition of diet and metabolic status of this child close to the time of death. The data includes increments influenced by pre-birth isotope ratios (prior to the line)

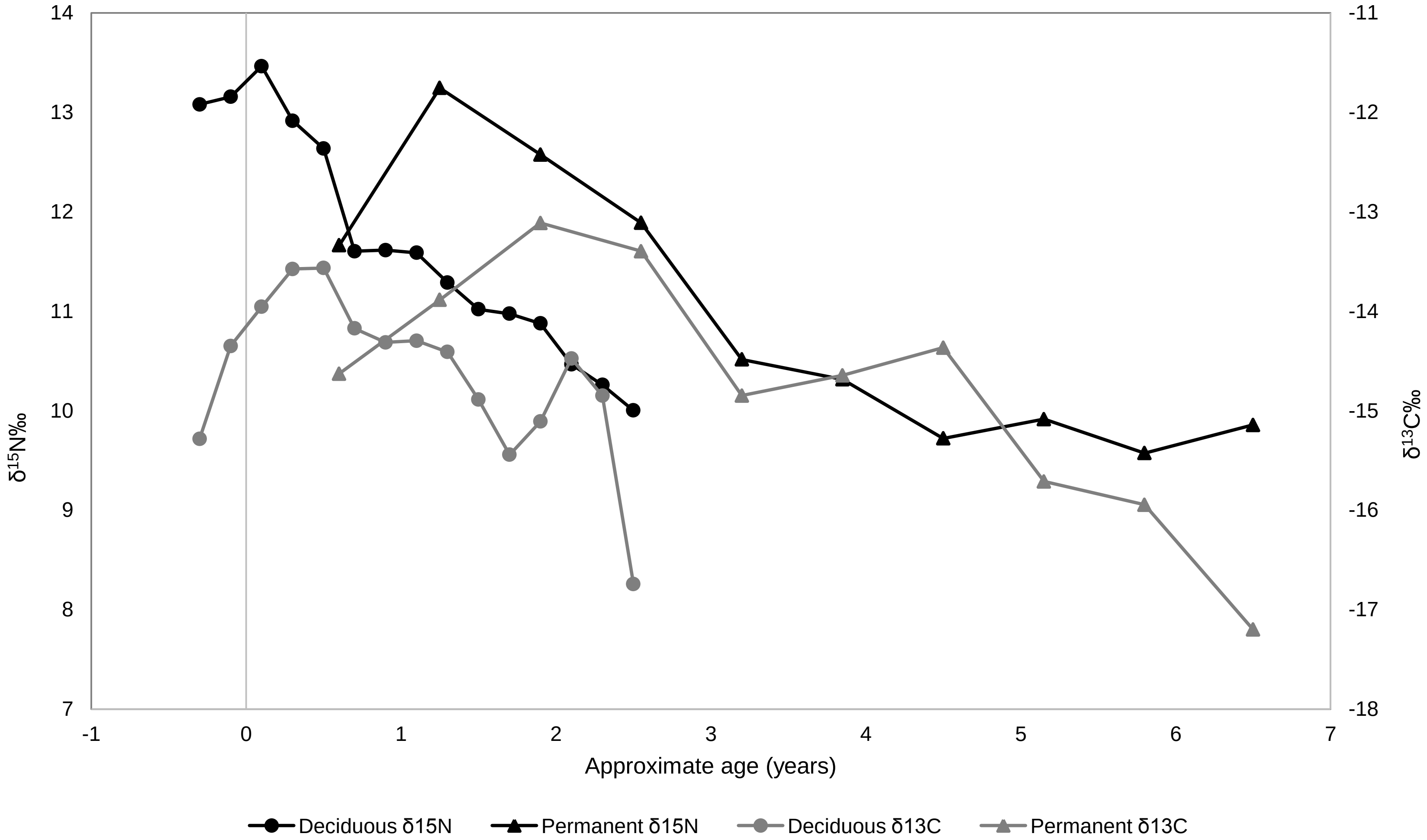

Figure 6.44. A plot of δ^{13}C and δ^{15}N incremental dentine profiles, from the deciduous and permanent first molars, Obrežje grave 12664. The data includes increments influenced by pre-birth isotope ratios (prior to the line). This individual died prior to the completed development of the permanent first molar and so this profile ends at c.6.5 years of age.

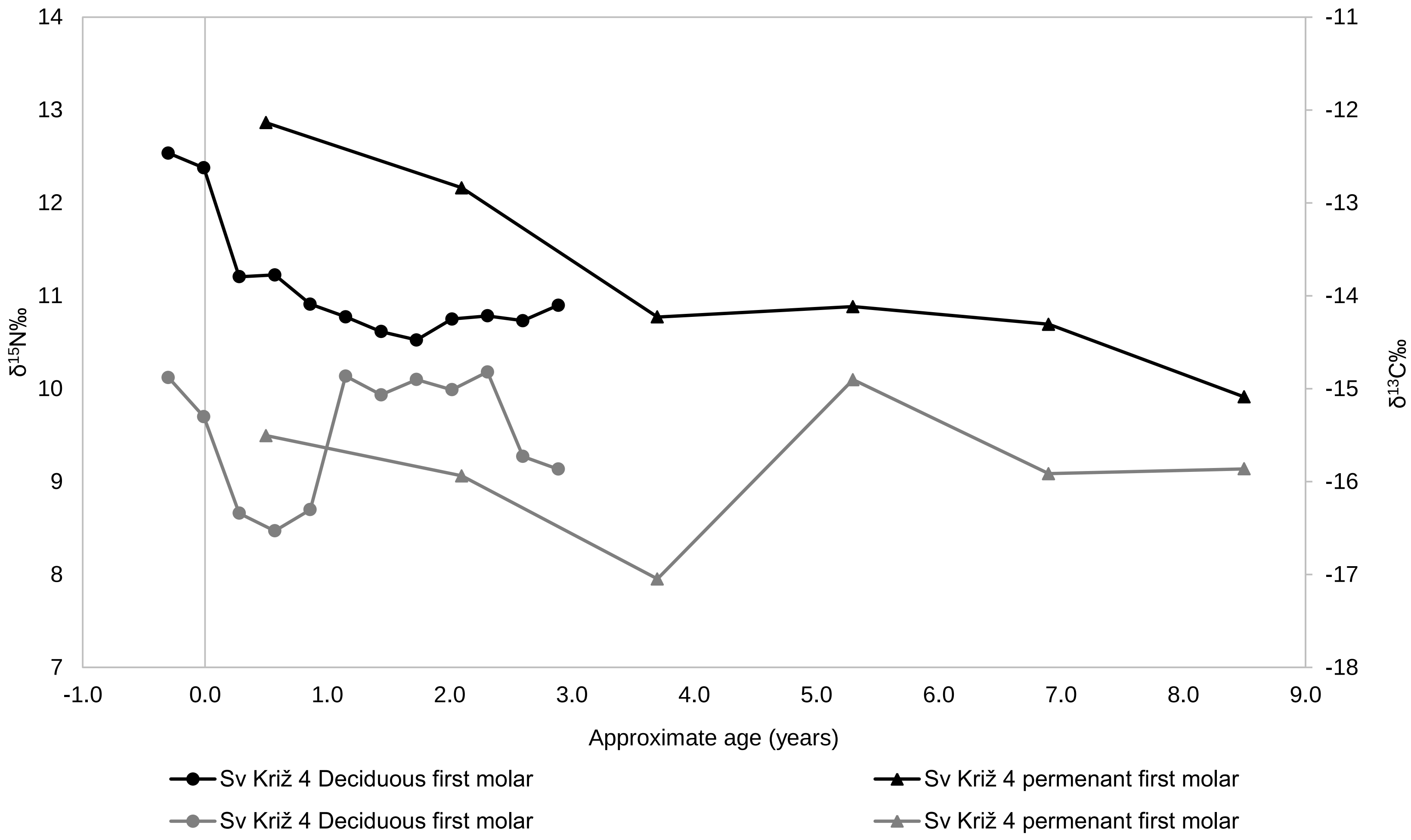

Figure 6.45. A plot of $\delta^{13}C$ and $\delta^{15}N$ incremental dentine profiles, from deciduous and permanent first molars, Sv Križ Grave 4. The data includes increments influenced by pre-birth isotope ratios (prior to the line). Due to the co-mingled nature of the remains from this site, it is less certain whether these two teeth represent the isotope profiles of the same individual.

The shift from higher to lower $\delta^{15}N$ values in association with decreasing $\delta^{13}C$ values in the early dentine increments may be indicating the onset of weaning and the introduction of solid foods (Millard 2000; Fuller et al. 2006; Beaumont et al. 2015). Throughout the period of weaning there is a shift in the relative importance of a lipid-rich, breast milk-based diet and one based on solid foods and an increased consumption of plants and animal products (Wright and Schwarcz 1999). This would be reflected in the forming tissues as a depletion of ^{15}N from reduced breast milk consumption, and a change in ^{13}C enrichment related to the addition of other food sources (Wright and Schwarcz 1999). On a C4 based diet, this would theoretically be reflected in the isotopic fluctuations in the dentine increments in both the deciduous and permanent teeth, resulting in lower $\delta^{15}N$ and higher $\delta^{13}C$ values (Wright and Schwarcz 1999). However, a net decrease in $\delta^{13}C$ values is observed throughout the development of both the deciduous and permanent teeth, suggesting a shift in protein sources from C4 to C3 (Tykot 2004; Beaumont and Montgomery 2016). This may be related to breastfeeding, where breast milk, initially being the sole source of protein, exhibits a C4 signal relative to the diet of the lactating mother (Wright and Schwarcz 1999; Beaumont et al. 2013b; Beaumont et al. 2015). As weaning is initiated, the infants are introduced to a wider range of proteins, including C3 based plants and animal products (as has already been discussed in Section 6.1, there is so far little evidence for the common use of millet for animal feed), which would subsequently result in the net decrease in $\delta^{13}C$ values observed between the initial increments of the deciduous teeth and the final increments of the permanent teeth (Wright and Schwarcz 1999).

This may be reflected in the teeth sampled for this study, as $\delta^{13}C$ and $\delta^{15}N$ values from the apex of permanent teeth are almost always lowest, for both teeth. This could be interpreted as a trophic level shift in $\delta^{15}N$ values as breast milk is eliminated from the diet, associated with a fall in the C4 signal, as diet becomes more varied, incorporating more C3 based foods (Wright and Schwarcz 1999; Millard 2000; Fuller et al. 2006).

6.3.6 Post-weaning

As has ready been discussed, there appears to be isotopic evidence for the onset of weaning during the formation of the permanent crowns, with $\delta^{15}N$ values plateauing around the age of five or six years of age. If this stage of development marks the cessation of breastfeeding, then the isotope ratios recorded in the dentine increments from this point onwards have the potential of reflecting the diet of the rest of the local population. From the age of roughly six years of age, $\delta^{15}N$ values remain mostly stable for many of the individuals between ~8‰ and 10.5‰. During this period of dentine development, the $\delta^{13}C$ values are seen to vary more noticeably, with some profiles continuing to display a net decrease in delta values, while others fluctuating between higher and lower $\delta^{13}C$ values. As can be observed in the plots displaying both $\delta^{13}C$ and $\delta^{15}N$ values, variations in carbon and nitrogen isotope ratios still appear to be occurring in unison, suggesting variable protein consumption after weaning (Beaumont et al. 2013b; Beaumont and Montgomery 2016).

It is important to consider when forming interpretations from these results, that the teeth sampled were taken from non-adult remains of individuals that did not survive into adolescence. Although no evidence (apart from Infant 1 buried at Zagorje ob Savi) was found on the skeletal remains to suggest metabolic disease, this does not necessarily mean that the death of these non-adults was unrelated to diet (Wood et al. 1992; DeWitte and Stojanowski 2015). The isotopic profile of Ljubljana Congress Square 1029 A, for example, exhibits $\delta^{15}N$ values at the end of their profile that are most likely related to metabolic stress (Hobson et al. 1993; Fuller et al. 2005; Kinaston et al. 2009; Beaumont et al. 2015). To assess whether the isotope ratios obtained from these individuals are reflective of, or a proxy for, population-wide diet, a larger sample of teeth taken from individuals who survived into adulthood should be taken. Nevertheless, the results of incremental analysis have highlighted the potential for dietary variation among and within communities, illustrated most in the variable $\delta^{13}C$ values, which likely reflects instability in the relative quantities of C3 and C4 based dietary components (Tykot 2004).

As this trend is seen from the Middle Bronze Age non-adult from Obrežje and in teeth dated to the Iron Age (Sv Križ 4 and Križna gora 75), it suggests that this is a pattern with a large spatial and temporal range. Therefore, it would appear that diet (post weaning) was more variable than perhaps the bulk collagen results would indicate, but that within a community, diet may have varied similarly among members of a population, supporting previous interpretations that diet was not controlled by biological (age or sex) or social codes.

6.3.7 Overview of incremental dentine

- In comparison to the isotopic homogeneity reflected in bulk collagen data, the use of incremental dentine analysis has highlighted isotopic variation over time, revealing perhaps a more complex situation
- Co-varying fluctuations in both $\delta^{13}C$ and $\delta^{15}N$ values were frequently observed
- Variations in $\delta^{13}C$ values within a single tooth root indicated variations in the quantities of C4 plants consumed over relatively short periods of dentine development
- Prior to weaning, fluctuations in isotopic ratios could also be reflective of the mother's diet and metabolic status, as well as that of the infant's
- Latter sections from permanent tooth roots, probably including isotope ratios of diet post weaning, show $\delta^{13}C$ and $\delta^{15}N$ continue to vary over time
- There is a probability that isotopic variation observed in incremental dentine sections is the result of a mix of dietary and metabolic influences
- Overall, it is difficult to pinpoint specific causes of isotopic variation from dentine increments

Unfortunately, as only the teeth of individuals who died in childhood were selected for incremental dentine analysis (except the Horseman from Sv Križ), it is difficult to argue whether those surviving into adulthood were following a similar subsistence strategy. However, the prevalence of this trend across multiple sites and time periods, in conjunction with the lack of osteological evidence for metabolic disease from any of the children (except the infant from Zagorje), suggests that these patterned shifts in isotope ratios are the result of a wide-ranging subsistence strategy. Moreover, the one dentine profile obtained from an individual that did survive into adulthood (Sv Križ, The Horseman) similarly displays swings from higher to lower $\delta^{13}C$ values throughout the development of their tooth.

6.4 Enamel carbonate

Following the analysis of bulk collagen and incremental dentine for $\delta^{13}C$ and $\delta^{15}N$ values, it became apparent that the diet of those inhabiting the ENTRANS study area throughout the Late Bronze Age and Early Iron Age was more complex than previously thought. To explore the subtle differences in isotope ratios further, dental enamel samples from individuals dying in childhood and surviving into adulthood were taken to explore the whole diet, through the investigation of carbonate carbon.

The results of enamel carbonate analysis can be found in Tables 6.13 and 6.14. Figures 6.46 to 6.57, and Appendix F, Disk 1. Due to the other strands of evidence available, Križna gora, Dolge njive and Obrežje are addressed in more detail in this section of the thesis.

Site	*Mean $\delta^{13}C_{carb}$ VPDB ‰*	*Standard deviation*
Dolge njive (n=9)	-8.5	1.1
Križna gora (n=25)	-7.4	1.4
Ljubljana Congress Square (n=5)	-7.7	0.7
Obrežje (n=6)	-8.5	3.1
Zagorje ob Savi (n=2)	-6.5	0.1
Grofove njive (n=4)	-10.1	1.1
Metlika/hrib (n=2)	-6.8	0.9
Sv Križ (n=7)	-7.8	1.7

Table 6.13. Mean $\delta^{13}C_{carb}$ values from enamel carbonate samples, separated by site

Site	*Mean $\Delta^{13}C_{carb-coll}$ ‰*	*Standard deviation*
Sv Križ (n=3)	*6.3*	*0.6*
Congress Square (n=3)	*6.4*	*0.3*
Obrežje (n=6)	*6.7*	*1.7*
Grofove njive (n=3)	*7.1*	*0.6*
Metlika (n=2)	*7.8*	*0.1*
Križna gora (n=25)	*8.1*	*1.2*
Zagorje (n=2)	*8.1*	*0.1*
Dataset (n=52)	*7.4*	*1.4*

Table 6.14. Mean $\Delta^{13}C_{carb-coll}$ values and Standard Deviations calculated from all of the $\Delta^{13}C_{carb-coll}$ values of individual sites

As illustrated in Figures 6.46 to 6.50, the $\Delta^{13}C_{coll-carb}$ values are consistently above 4‰ (except for Obrežje 3043, which is explained in Section 6.4.3) According to Ambrose (1997), this indicates that the individuals included as part of the ENTRANS project were eating a diet which included a high proportion of C4 carbohydrates and terrestrial protein (Finucane et al. 2006; Loftus and Sealy 2012). This is consistent with the results of previous carbon and nitrogen isotope analyses.

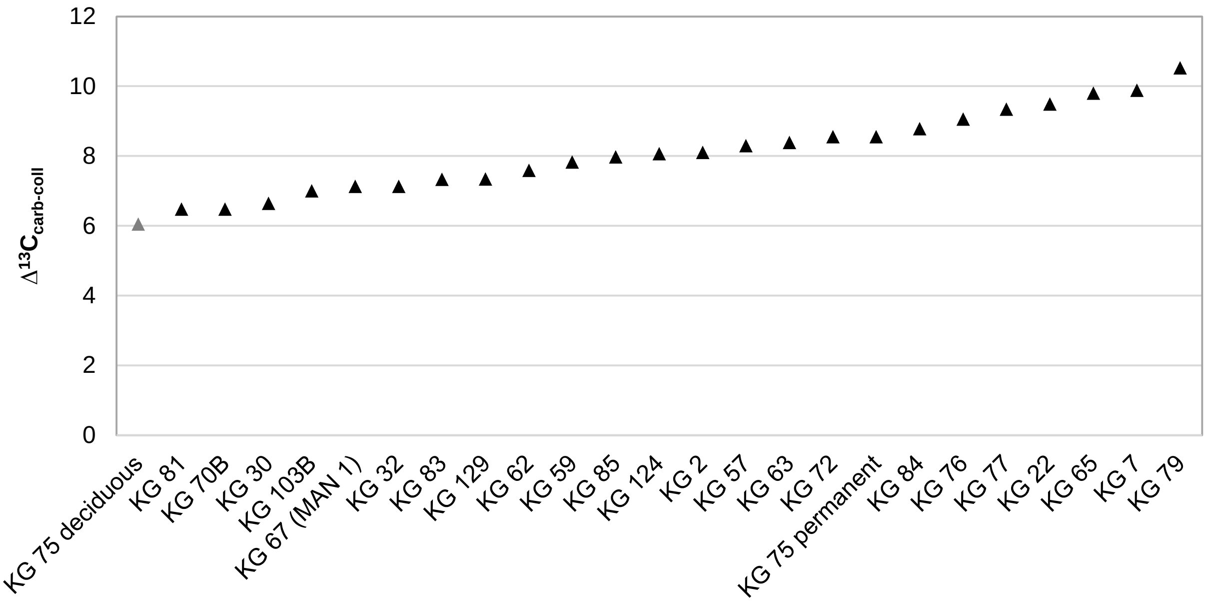

Figure 6.46. A plot of $\Delta^{13}C_{carb-coll}$ values from tooth dentine and enamel for individuals from Križna gora (n=25)

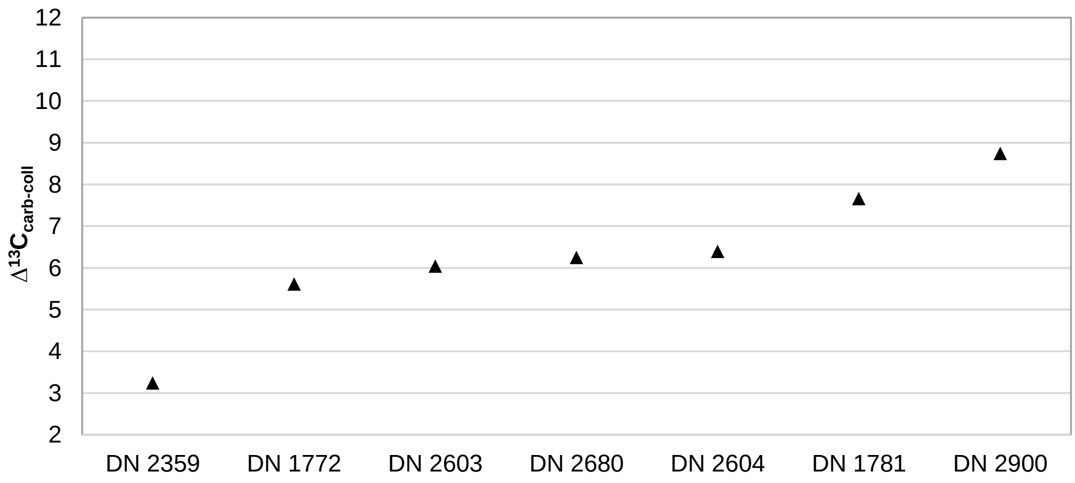

Figure 6.47. A plot of $\Delta^{13}C_{carb-coll}$ values for individuals from Dolge njive (n=7)

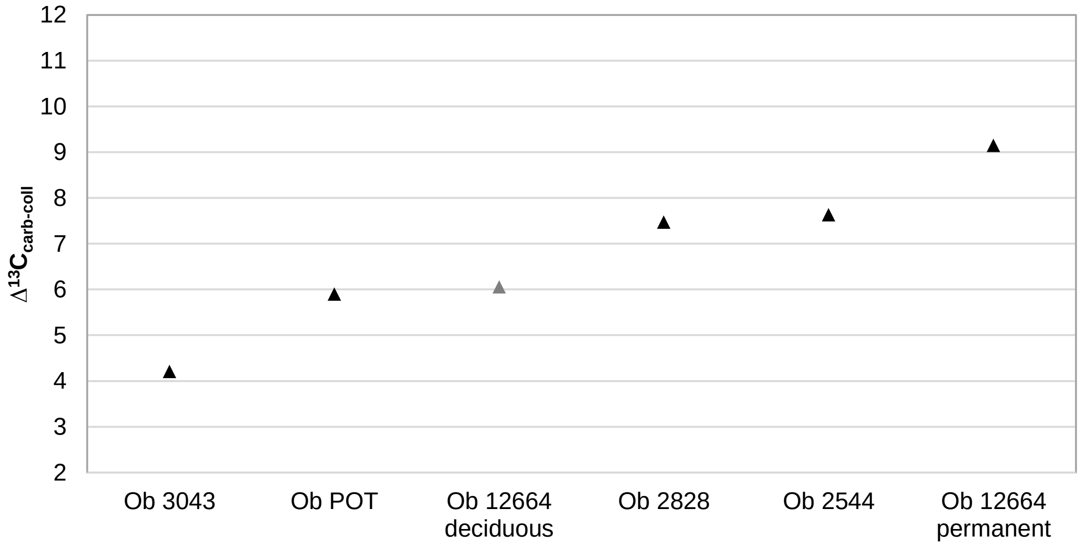

Figure 6.48.A plot of $\Delta^{13}C_{carb\text{-}coll}$ values for individuals from Obrežje (n=6)

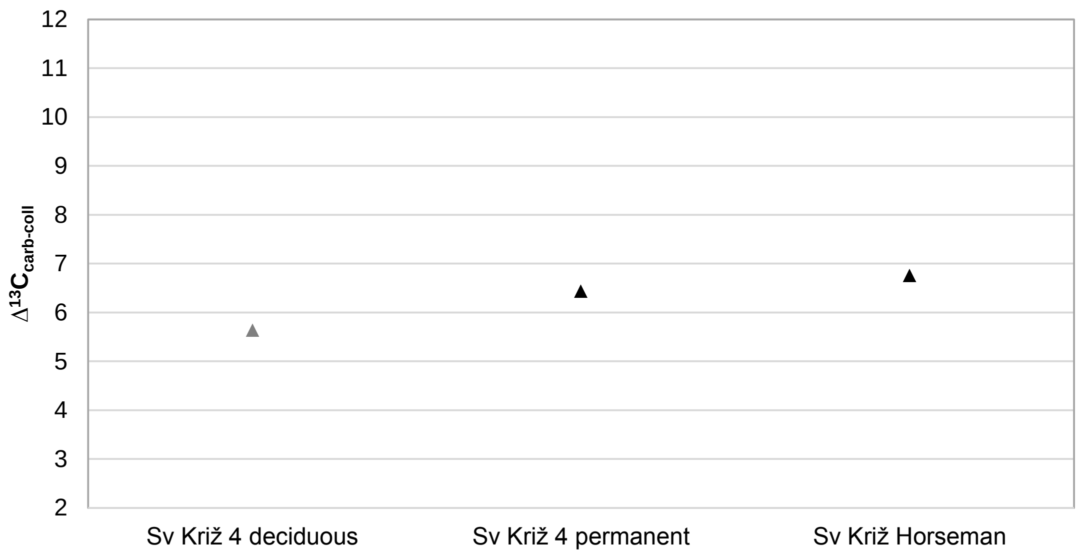

Figure 6.49.A plot of $\Delta^{13}C_{carb\text{-}coll}$ values for individuals from Sv Križ (n=3)

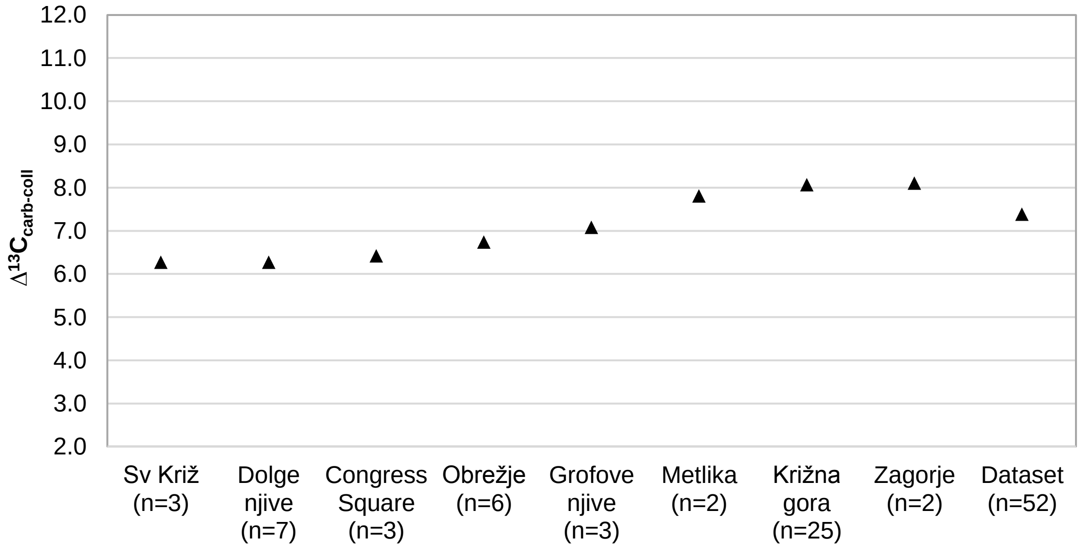

Figure 6.50. A plot of mean $\Delta^{13}C_{carb\text{-}coll}$ values for the whole ENTRANS dataset (n=52) and by the site. All mean $\Delta^{13}C_{carb\text{-}coll}$ values fall above 4‰, which is evidence for the consumption of C4 carbohydrates and terrestrial protein (Ambrose 1997)

6.4.1 Enamel carbonate carbon model

Presentation of results: carbonate carbon modelling

To further understand the relationship between $\delta^{13}C_{carb}$ and $\delta^{13}C_{coll}$ values collected as part of the ENTRANS project, they have been plotted against one another in Figures 6.52 to 6.57. Overlaying these plots is the model of regression lines developed by Kellner and Schoeninger (2007), which have been further adapted by Froehle et al. (2010). These regression lines represent different carbon isotope protein and energy sources (i.e. C3 plant protein and C4 plant protein). Values falling on or near the C3 protein line would have incorporated protein based on a C3 based diet (including protein from animals consuming a C3 diet), whilst individuals falling on or near the C4 protein line would have consumed a diet based on C4 protein (Kellner and Schoeninger 2007; Froehle et al. 2010). Values falling between these regression lines would have ingested a diet including carbon from both protein sources. Individuals consuming marine-based protein could also fall between these two lines, but as already stated in Section 1.4, there is no indication, cultural or faunal, that these populations were ingesting marine foods (Kellner and Schoeninger 2007; Froehle et al. 2010).

As the carbonate fraction of the tooth enamel primarily incorporates carbon from the energy aspect of the diet (carbohydrates, lipids, and to a lesser extent, protein), the location of values on the x-axis of the plot is more reflective of the whole diet (Kellner and Schoeninger 2007; Froehle et al. 2010). More positive values are indicative of a C4 based energy source, while more negative values are indicative of a C3 based energy source (Kellner and Schoeninger 2007; Froehle et al. 2010). A basic schematic of the model can be observed in Figure 6.51.

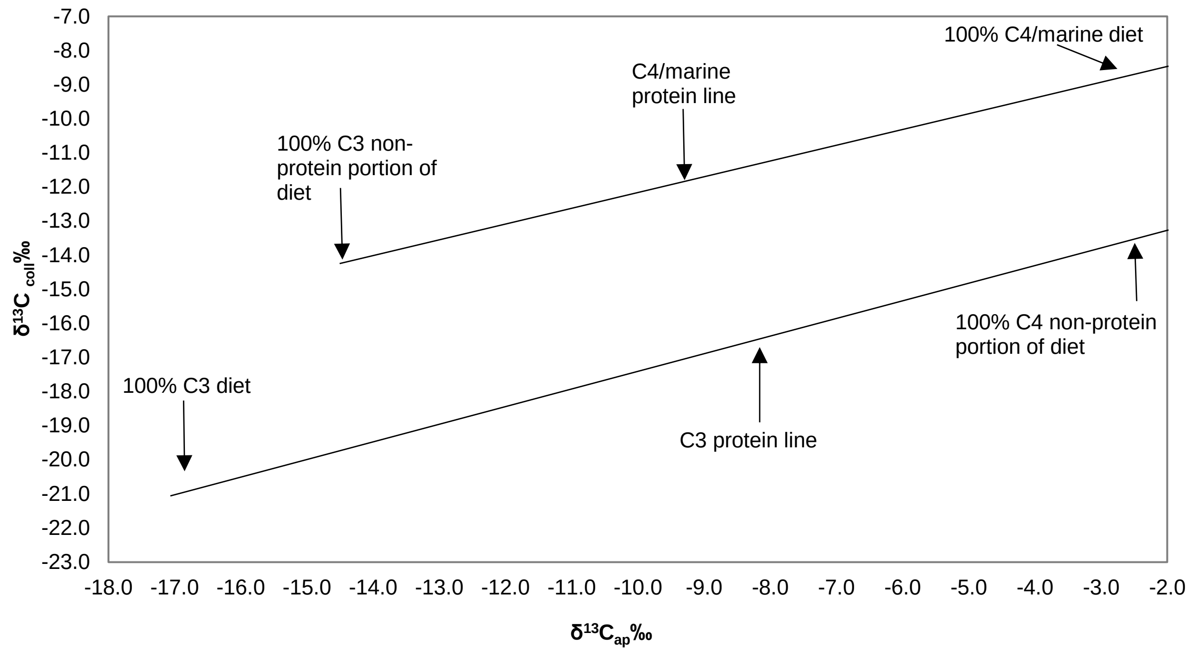

Figure 6.51. A schematic of the Froehle et al. (2010) carbon model comparing collagen and carbonate values, based on the previous model created by Kellner and Schoeninger (2007).

The use of carbonate from tooth enamel instead of bone apatite, which this model was originally produced with, created questions as to how far the model could be reliable, as the relationship between the two tissues is still not fully understood (Kellner and Schoeninger 2007). The use of $\delta^{13}C_{bone\ apatite}$ values in the original model was not used to indicate a relationship between $\delta^{13}C_{collagen}$ and $\delta^{13}C_{bone\ apatite}$ values, but a “functional” relationship, where $\delta^{13}C_{diet}$ values are substituted for $\delta^{13}C_{bone\ apatite}$ values because of their strong correlation (R^2 = 0.97) (Kellner and Schoeninger 2007; Froehle et al. 2010). Loftus and Sealy (2012) have reported a weak correlation between tooth enamel and bone apatite values (R^2 = 0.37), with no apparent, systematic offset between the two tissues. They also found that $\Delta^{13}C_{collagen\text{-}enamel}$ values could not be equated to

$\Delta^{13}C_{collagen\text{-}bone\ apatite}$ values. However, they did argue that, because enamel and bone apatite both source their structural components from the same pool of carbonate and bicarbonate dissolved in the blood, any differences between the two tissues are unlikely to be the result of differential routing of dietary macronutrients (Lee–Thorp 2002; Lee-Thorp 2008; Loftus and Sealy 2012). It was more likely that differences in $\delta^{13}C_{bone\ apatite}$ and $\delta^{13}C_{enamel\ carbonate}$ values were the result of the diagenetic change to the bone apatite in the burial environment (Loftus and Sealy 2012).

To assess whether the trends identified using dental enamel were behaving in a similar manner to the bone apatite included as part of the models by Kellner and Schoeninger (2007) and Froehle et al. (2012), a separate and wholly unrelated data set has been plotted alongside the ENTRANS data set in Figure 6.52. When compared to a data set of an Italian Samnite population (completed by the author as part of a Master of Science dissertation), dating to the 6th century BC and known to have subsisted on a C3 based diet, many ENTRANS samples are notably different. The Italian samples fall in a position consistent with a C3 based diet on the model, both on the C3 protein line and close to the 100% C3 diet position on the x-axis. This supports the argument that the individuals making up the ENTRANS dataset were consuming a substantial quantity of C4 based carbon (primarily in the non-protein portion of the diet), and that the model is working as expected.

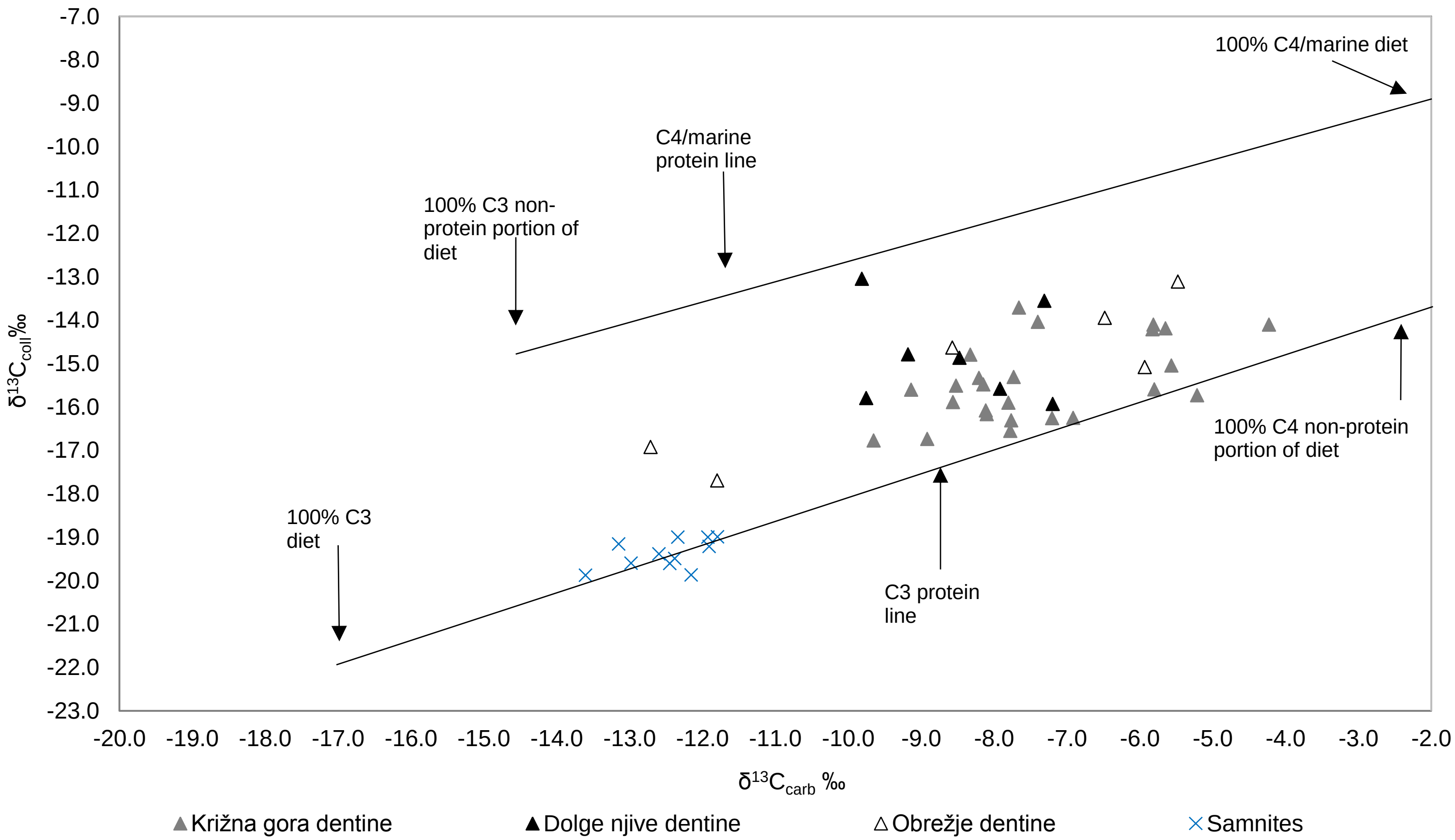

Figure 6.52. A plot of $\delta^{13}C_{coll}$ and $\delta^{13}C_{carb}$ values from the sites of Križna gora (n=31), Dolge njive (n=2) and Obrežje (n=6), compared with the Froehle et al. (2010) carbon model. The whole tooth means generated from incremental dentine values from a separate, Samnite dataset (n=11) has been added as a C3 diet comparison. These data points cluster tightly on the C3 protein line and close to the 100% C3 diet position. This supports the hypothesis that the ENTRANS individuals were consuming a high quantity of C4 non-protein and a mix of C3 and C4 based proteins. The comparison of the two datasets also indicates that the model is working as expected with the use of enamel carbonate, rather than bone apatite.

6.4.2 Enamel carbonate: regional carbon model

When all the ENTRANS $\delta^{13}C_{carb}$ and $\delta^{13}C_{coll}$ values are displayed in this model, as in Figure 6.53, most data points cluster between the two protein lines, and in the right half of the plot. This indicates that individuals were consuming a mixture of both C3 and C4 based proteins and energy sources (Kellner and Schoeninger 2007; Froehle et al. 2010). This supports the carbon and nitrogen isotope analysis, previously discussed in Section 6.2.

The range of values seen in this model does suggest that there is some variation in the focus of different carbon sources. Although all individuals appear to display a mix of carbon sources, some are focussed more primarily on C3 protein than others (Kellner and Schoeninger 2007; Froehle et al. 2010). These subtle variations are more visible at the site level. The $\delta^{13}C_{carb}$ and $\delta^{13}C_{coll}$ datasets from Križna gora, Dolge njive and Obrežje have been modelled in Figures 6.53 to 6.56.

6.4.3 Enamel carbonate carbon models: Križna gora, Dolge njive and Obrežje

Križna gora

The carbon isotope ratios of dental tissues obtained from Križna gora (Figure 6.54) show a similar, but more constrained, spread of carbon isotope ratios when compared to the other two sites, with a very weak correlation (R^2 = 0.29) and some individuals falling closer to the C3 protein line than others. In addition to this, there appears to be a separation in the $\delta^{13}C_{carb}$ values between two clusters of data points on the x-axis. The first cluster falls between -9.6‰ and -6.9‰ and the second between -5.8‰ and -4.2‰. This separation will be addressed again in Section 6.5.2.

Overall, this cemetery group have provided evidence for a mix of protein and non-protein components. The spread of data suggests that even though every individual was consuming a mix of both C3 and C4 carbon, there is a variance in the relative amount of each type ingested (Kellner and Schoeninger 2007; Froehle et al. 2010).

Dolge njive

As presented in Figure 6.55, the $\delta^{13}C_{carb}$ and $\delta^{13}C_{coll}$ (dentine) values from individuals analysed from the cemetery site of Dolge njive are widely scattered between the two protein lines, with no correlation ($R^2 = 0.04$). This suggests that there was also a variation in both the protein and non-protein dietary components consumed by those buried at this site, with the majority ingesting a significant amount of protein with a mix of C3 and C4 signatures (Kellner and Schoeninger 2007; Froehle et al. 2010).

Obrežje

The few samples obtained from the cemetery site of Obrežje show the largest separation of $\delta^{13}C_{carb}$ values (Figure 6.56). Two points, ranging from -11.8‰ to -12.7‰, are distinctly different from the rest of ENTRANS enamel carbonate dataset. There is a strong correlation between all the data points from Obrežje ($R^2 = 0.81$). This suggests that these individuals were consuming a similar mix of carbon from both C4 and C3 based proteins, but that the two individuals buried in Grave 3043 (Middle Bronze Age) were sourcing more of their energy, or whole-diet, from a C3 base than was being ingested by the remaining individuals, who appear to have focussed more heavily on C4 (Kellner and Schoeninger 2007; Froehle et al. 2010).

The data point falling closest to the C3 protein line has been linked with the $\delta^{13}C_{carb}$ value of -8.6‰ and the $\delta^{13}C_{coll}$ value of-14.6‰ because they represent the deciduous and permanent tooth from the same individual: Obrežje 12664. The shift in both the $\delta^{13}C_{carb}$ values and the $\delta^{13}C_{coll}$ values between the two teeth is evidence to suggest significant intra-individual variation in carbon sources throughout life, as also reflected in the incremental dentine analysis in Section 6.3.5 (Kellner and Schoeninger 2007; Froehle et al. 2010). This separation in $\delta^{13}C_{carb}$ and $\delta^{13}C_{coll}$ values is further explored below in Section 6.5.4.

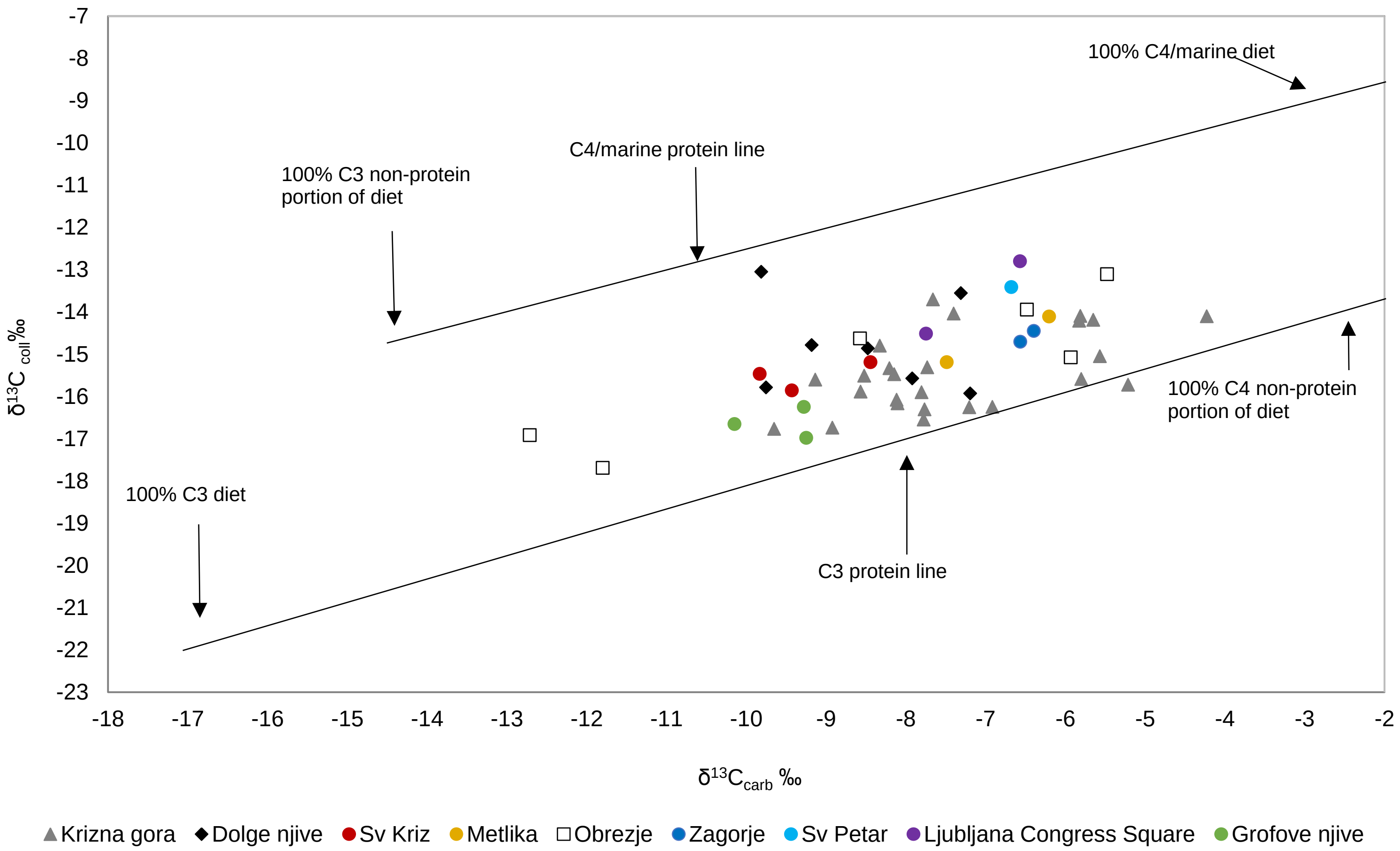

Figure 6.53. A plot of $\delta^{13}C_{coll}$ and $\delta^{13}C_{carb}$ values from the whole human ENTRANS dataset, compared with the Froehle et al. (2010) carbon model. Individual sites have been colour coded for clarity. Križna *gora (triangles), Dolge njive (diamonds) and* Obrežje *(squares) have been additionally highlighted through the use of symbols because they constitute case studies addressed in more detail throughout this chapter, as well as throughout the thesis as a whole.*

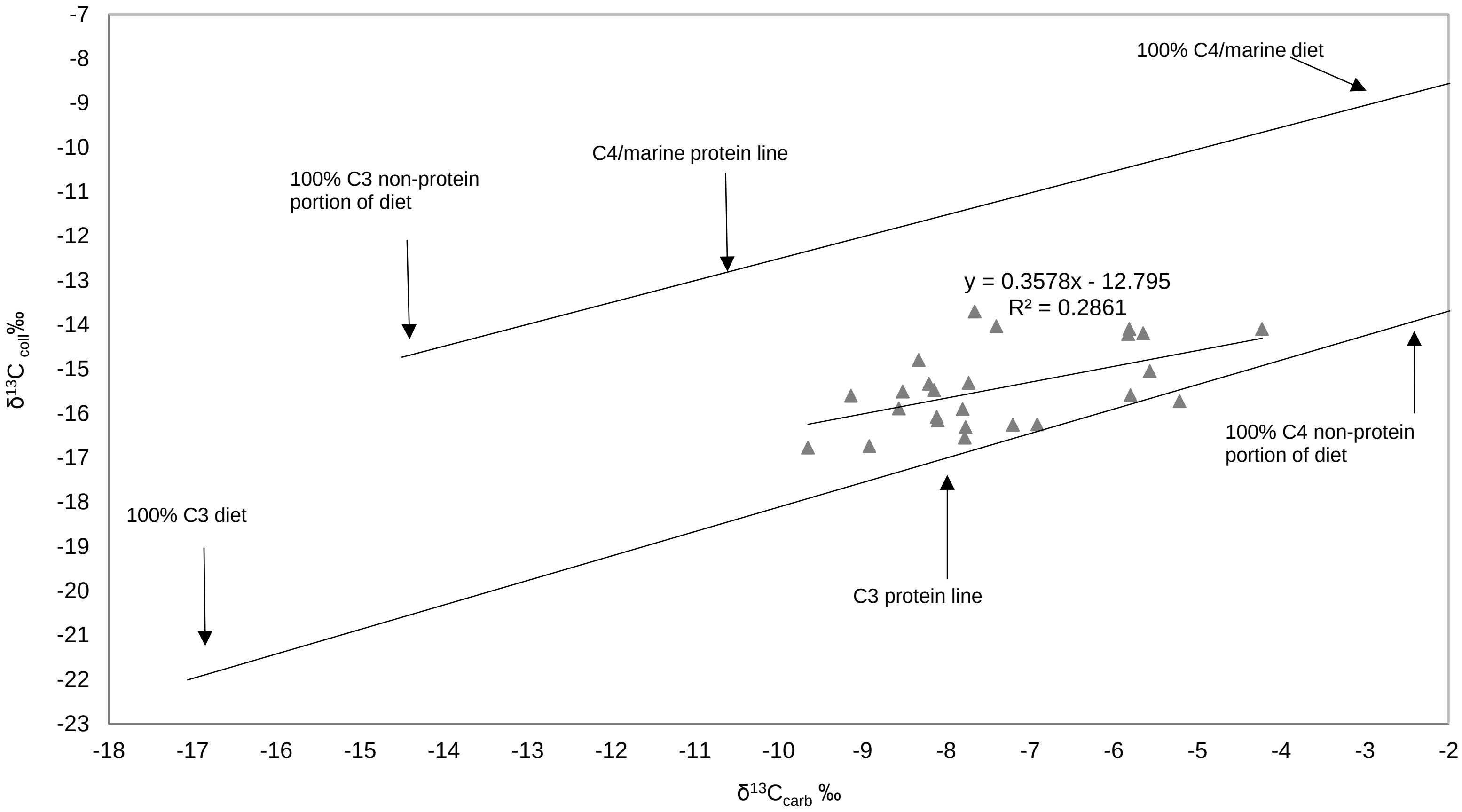

Figure 6.54. A plot of δ$^{13}C_{coll}$ and δ$^{13}C_{carb}$ values from the site of Križna gora compared with the Froehle et al. (2010) carbon model.

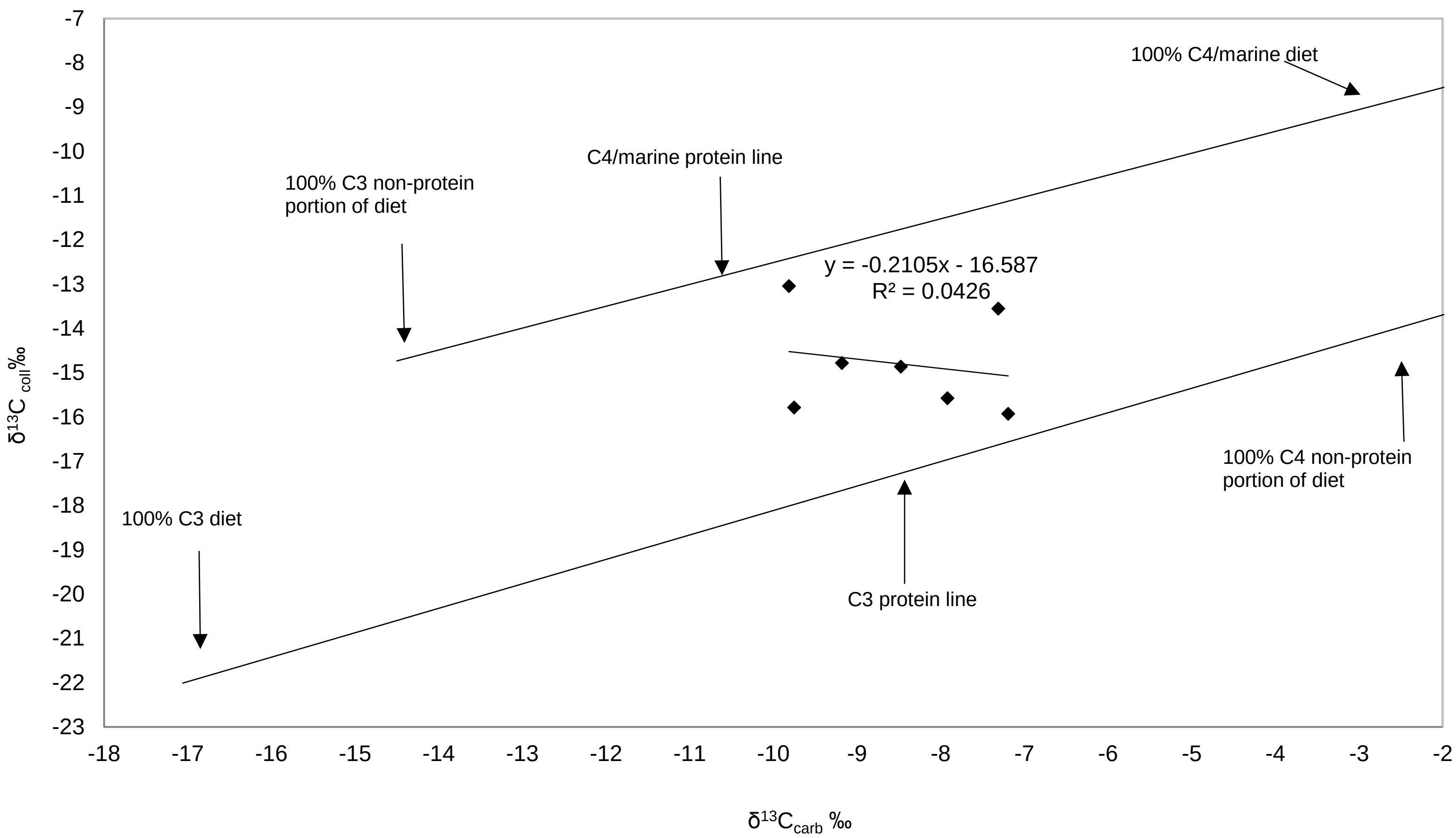

Figure 6.55. A plot of $\delta^{13}C_{coll}$ and $\delta^{13}C_{carb}$ values from the site of Dolge njive, compared with the Froehle et al. (2010) carbon model.

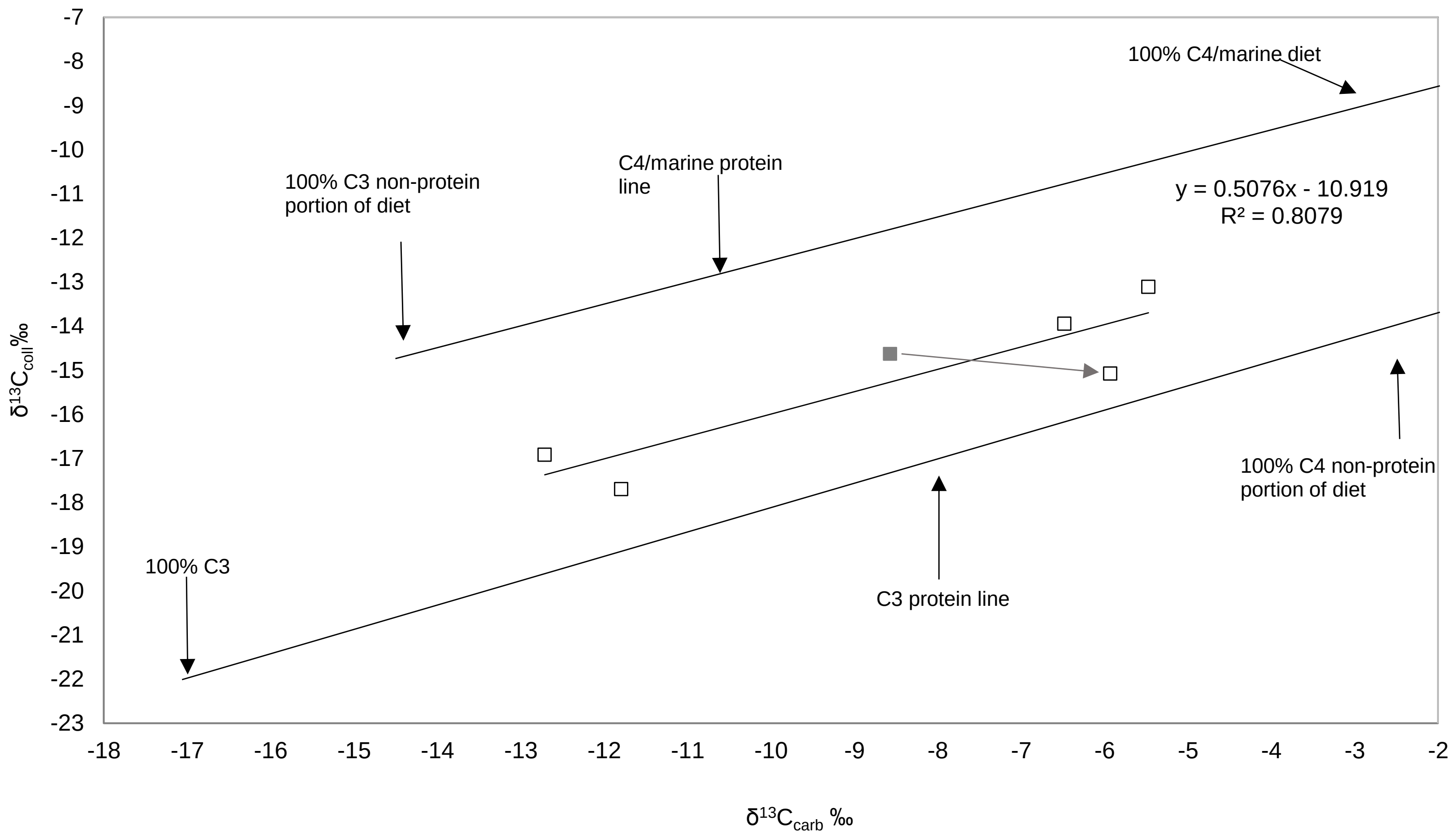

Figure 6.56. A plot of $\delta^{13}C_{coll}$ and $\delta^{13}C_{carb}$ values from the site of Obrežje, compared with the Froehle et al. (2010) carbon model.The white squares represent delta values from permanent teeth and the grey square represents isotope ratios from a deciduous tooth. The arrow indicates the permanent and deciduous teeth from individual 12664.

6.4.4 Deciduous and permanent teeth

When deciduous and permanent teeth from the same individual are modelled together, as has been done in Figure 6.57, a consistent shift can be identified in both the $\delta^{13}C_{carb}$ and $\delta^{13}C_{coll}$ values. $\delta^{13}C_{coll}$ values are observed to slightly decrease, while $\delta^{13}C_{carb}$ values increase. This shift reflects a change in whole-diet during the development of the two teeth, with the C4 non-protein aspect of the diet seemingly becoming more dominant (Kellner and Schoeninger 2007; Froehle et al. 2010). This could be reflecting the transition from breast milk to solid foods, which seem to have focussed upon C4 carbohydrates (Wright and Schwarcz 1998; Wright and Schwarcz 1999). This phenomenon is revisited later in the chapter, under the theme of Childhood diet in Section 6.5.4.

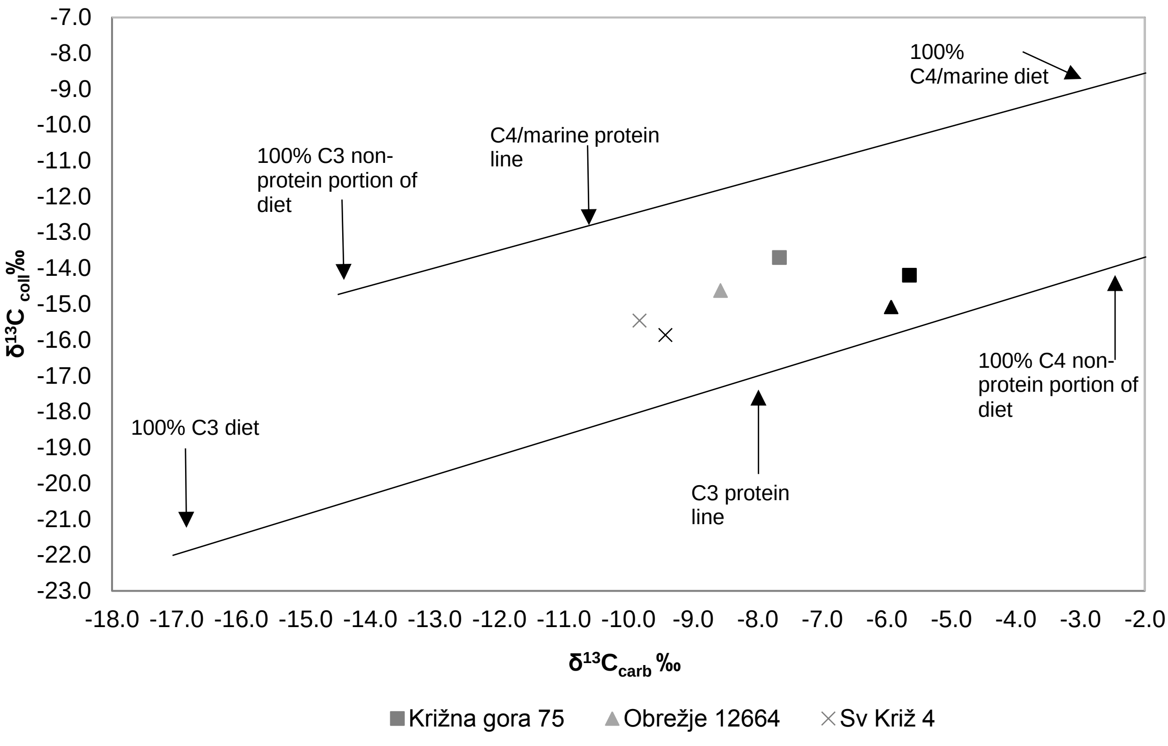

Figure 6.57.A plot of $\delta^{13}C_{coll}$ and $\delta^{13}C_{carb}$ values, from deciduous and permanent tooth enamel, from Križna gora (Grave 75), Obrežje (Grave 12664) and Sv Križ (Grave 4). The data has been compared with the Froehle et al. (2010) carbon model. *Grey symbols represent deciduous teeth and black symbols represent permanent teeth. A consistent shift in the $\delta^{13}C_{carb}$ values can be identified between the deciduous and permanent teeth. $\delta^{13}C_{carb}$ values from deciduous tooth enamel are consistently lower than paired permanent tooth enamel. This indicates enrichment in ^{13}C in permanent teeth, relative to deciduous teeth*

6.5 Thematic interpretations combining multiple carbon and nitrogen isotopic methods

6.5.1 Chronology

The isotopic datasets from Križna gora and Dolge njive largely overlap in their chronology, with radiocarbon dates between c.900 and c.400cal BC (see Section 2.2). The similar variability in their isotopic ratios (collagen and carbonate) indicates that similar dietary components dominated the Early Iron Age. Conversely, as has been previously discussed in Section 2.2, the results of radiocarbon dating have shown that the individuals buried at Obrežje spanned a significant time period, from the Late-Middle Bronze Age to the Iron Age. Although the C4 signal is less apparent in the individuals dating to the Bronze Age (Figure 6.56) in relation to the rest of the ENTRANS dataset, the range of values produced is evidence for the consumption of millet as early as the Middle Bronze Age at this site (Tykot 2004). This interpretation is maintained when the male from Sv Petar Ludbreški (1960) is also compared to the Obrežje individuals (Figures 6.53 and 6.54), as the $\delta^{13}C$ values produced by this individual (Apex dentine: -13.4‰; rib: -15.2‰) are indicative of C4 consumption (Tykot 2004).

This evidence of C4 consumption during the Bronze Age has similarly been supported by the enamel carbonate data from Obrežje, where samples taken from Middle and Late Bronze Age individuals have plotted in an area associated with a mix of C3 and C4 based protein and non-protein (Kellner and Schoeninger 2007; Froehle et al. 2010). Because of the very small Bronze Age data set, it is not possible to suggest to what extent these values can be used to establish a “typical diet” for the period. Nevertheless, the identification of probable C4 plant consumption during this time provides a foundation for future enquiry.

6.5.2 Sex

Križna gora

Although no sex-based differences were identified in the initial carbon and nitrogen, bulk collagen isotope analysis (and the children sampled for incremental dentine analysis were not biologically sexed), some subtle variation may be detectable in the enamel carbonate results from Križna gora.

As presented as a box and whisker plot in Figure 6.58 and Table 6.15, the data could be linked to the sex of the individuals. Although the mean and median values of the three sex-based categories are similar, the data obtained from the Female category shows a greater variation, with an increased spread of data and noticeably higher $\delta^{13}C_{carb}$ values than either the Male or Non-adult categories, with delta values as high as -4.2‰. This has been highlighted in the IQR values, which are >1‰ larger in the Female category, relative to the Male and Non-adult categories.

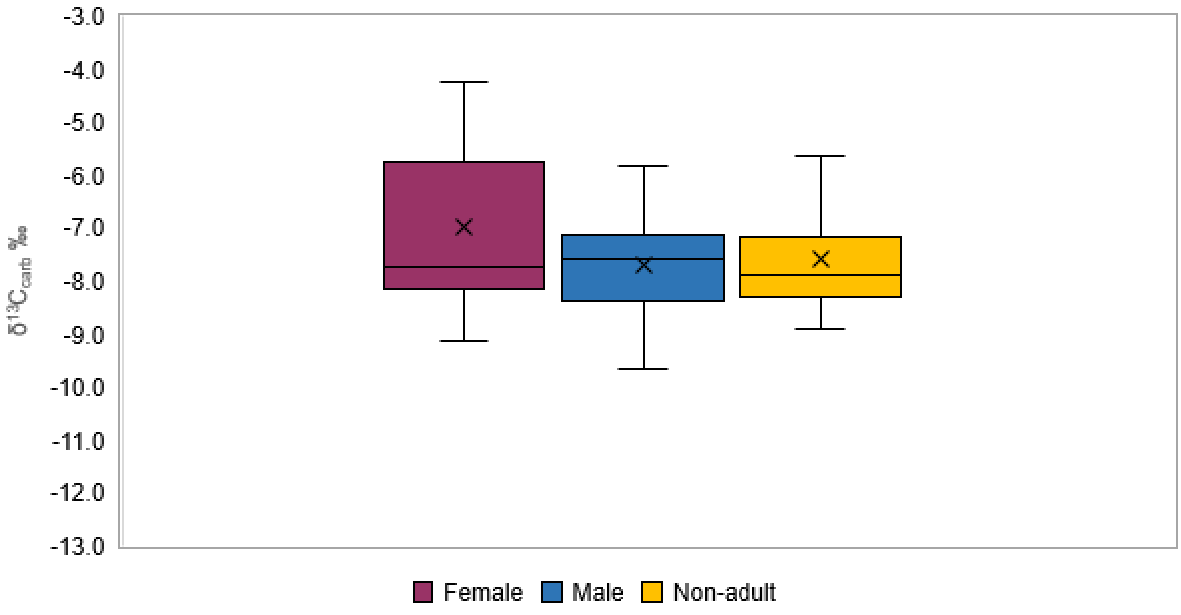

Figure 6.58 $\delta^{13}C_{coll}$ values divided by sex. Non-adult individuals but were not assessed for sex because of methodological limitations.

$\delta^{13}C_{carb}$ ‰	Mean	Standard deviation	Q1	Q3	IQR
Female	-7.0	1.6	-5.7	-8.1	2.4
Male	-7.7	1.2	-7.1	-8.4	1.3
Non-adult	-7.6	1.4	-7.2	-8.3	1.1

Table 6.15. Mean, standard deviation, first and third quartile, and interquartile ranges of $\delta^{13}C_{carb}$ values, separated by sex.

When these $\delta^{13}C_{carb}$ values are modelled against $\delta^{13}C_{coll}$ values (see Figure 59), these higher $\delta^{13}C_{carb}$ values produced by the female enamel carbonate (Cluster 2) are found closer to the 100% C4 non-protein position than the remaining Križna gora enamel carbonate data set. Subsequently, this could be indicative of sex-based dietary differences, with some females consuming higher quantities of C4, non-protein based carbon than males (Kellner and Schoeninger 2007; Froehle et al. 2010).

It is important to note, however, that these isotope ratios have been obtained from dental tissues formed during childhood and only reflect dietary consumption during that time. Therefore, any dietary differences between males and females occurred during childhood and it cannot be said if this was maintained beyond the period of tooth formation. To investigate this potential difference further, a much greater number of tooth enamel sample is required for the application of inferential, statistical analyses. This is a biased and limited dataset, and this variation could be an artefact of this. Consequently, this tentative interpretation should be treated with caution. This small group of individuals does, nevertheless, illustrate the potential for sex-based variation in diet for future exploration.

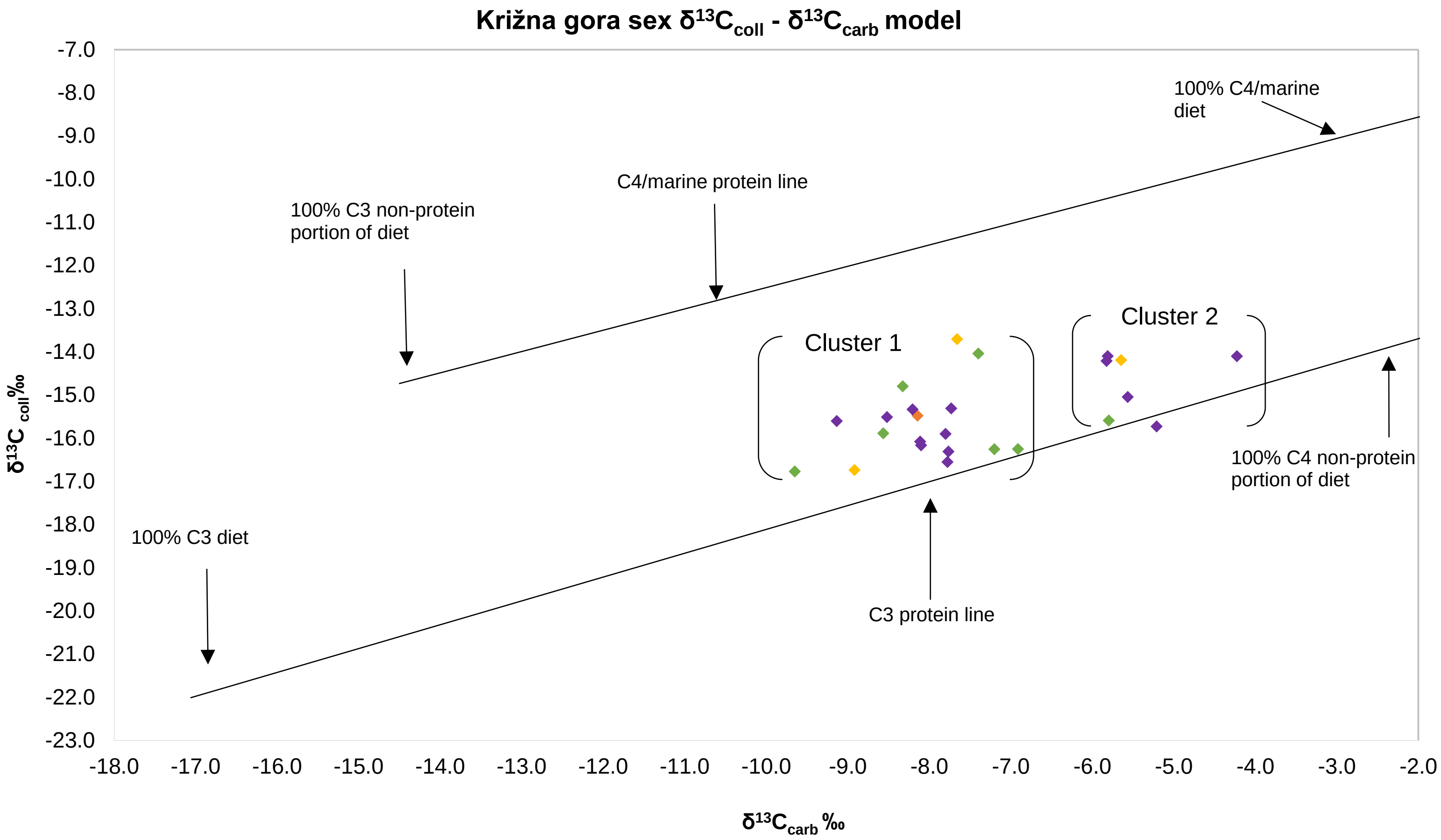

Figure 6.59. A plot of $\delta^{13}C_{coll}$ and $\delta^{13}C_{carb}$ values from the site of Križna gora, compared with the Froehle et al. (2010) carbon model. Individuals have been colour coded by biological sex and typological gender: green = male; purple = female; orange = unsexed; yellow = non-adult.

Dolge njive and Obrežje

From the site of Dolge njive, the small sample size and the inclusion of only one identifiable male (2680) has meant that the observation of potential variation in $\delta^{13}C_{carb}$ values and $\delta^{13}C_{coll}$ values related to sex is not possible. Similarly, the individuals buried at Obrežje are an unrepresentative dataset based on both sample size and chronology, with 3043 and the Pot individual buried with 3043 Radiocarbon dated to the Late Bronze Age, 12664 to the Middle Bronze Age, and 2544 dated to the early Iron Age.

6.5.3 Age at death

As has already been indicated by the broadly homogenous data set produced by the bulk collagen analysis of adult remains, there are no obvious distinctions between different Age at Death categories. There was similarly no clear patterning observed between age at death and $\delta^{13}C_{carb}$ and $\delta^{13}C_{coll}$ values, which corresponds to the carbon and nitrogen isotope analysis. This is not particularly surprising, as enamel and apex dentine samples are roughly reflecting the same developmental stage, as the teeth are forming in infancy and childhood. Most individuals included in this study survived into adulthood, and therefore any dietary differences between adult individuals are not reflected in these carbon isotope ratios.

The most apparent differences in isotope ratios from the ENTRANS human dataset were obtained from non-adult remains, with the most distinct outliers being the two infants buried at Zagorje ob Savi.

6.5.4 Childhood diet

As already exhibited in the $\delta^{13}C$ and $\delta^{15}N$ values from bulk collagen and incremental dentine analysis, as well as the $\delta^{13}C_{carb}$ and $\delta^{13}C_{coll}$ model for the deciduous and permanent teeth from the non-adult individuals, high-resolution isotopic techniques are revealing a more nuanced understanding of the diet of the people inhabiting this study area in prehistory.

The isotopic variation that is being obscured in the bulk collagen samples can be once again viewed in the $\delta^{13}C_{carb}$ and $\delta^{13}C_{coll}$ values modelled from the dentine taken from the non-adults of this investigation. When deciduous and permanent teeth from a single individual are compared in this way, there is usually a similar spread in $\delta^{13}C_{coll}$ values, which has already been presented in the incremental dentine profiles. The $\delta^{13}C_{carb}$ values, however, are always more positive from the permanent teeth than the deciduous. This indicates that there is an increase in the C4 signal from the non-protein portion of the diet between the formation of the deciduous and permanent crown (Kellner and Schoeninger 2007; Froehle et al. 2010). As already discussed, there is expected to be a shift in diet at this point in development as children progress through significant life stages, including breastfeeding, weaning, the cessation of breastfeeding and the normalisation of diet to that of the rest of the adult population (assuming there was not a childhood specific diet) (Jay et al. 2008).

Breastfeeding and weaning

This increase in the $\delta^{13}C_{carb}$ values hints at an increase in C4 based non-protein in the permanent teeth relative to deciduous teeth. However, there is perhaps another cause for the differences observed between deciduous and permanent teeth.

It is thought that the breastmilk is systematically depleted in ^{13}C relative to the diet of the lactating mother because of fractionation during milk synthesis (Wright and Schwarcz 1998). Breast milk has a high lipid content, which provides a significant amount of energy to the nursing infant and, more importantly, dietary carbon (Wright and Schwarcz 1998). Dietary lipids tend to be isotopically lighter than other dietary components, such as carbohydrates (Wright and Schwarcz 1998). Therefore, diets with a high lipid content are more ^{13}C depleted than diets with a higher carbohydrate component, which are comparatively enriched in ^{13}C, resulting in higher $\delta^{13}C_{carb}$ values (Wright and Schwarcz 1998; Wright and Schwarcz 1999). Subsequently, a child consuming breastmilk only is likely to have lower $\delta^{13}C_{carb}$ values than a child that has begun to supplement their diet with carbohydrates (plants), which will have a significant effect on $\delta^{13}C_{carb}$ values (Wright and Schwarcz 1999). The bioapatite of the tooth enamel is believed to contain a significant amount of carbon sourced from this component of the diet in comparison to lipids and protein, and so the addition of this carbon source would have a substantial effect on $\delta^{13}C_{carb}$ values (Wright and Schwarcz 1998). If this carbohydrate is additionally sourced from C4 plants, then this enrichment in ^{13}C would be greater still, as lipids in breast milk are more likely to have been sourced from C3 sources, such as animal products, rather than from C4 plants (millet) (Wright and Schwarcz 1998; Wright and Schwarcz 1999).

If this hypothesis is applied to the paired deciduous and permanent teeth displayed in Figure 6.57, then the shift from lower to higher $\delta^{13}C_{carb}$ values could be interpreted as an addition of solid food to the diet during the period of enamel formation. As the enamel crown of the deciduous first molar is complete by approximately 7.5 months and the crown of the permanent first molar is complete at approximately 3.5 years of age, then it could be argued that the onset of weaning began before 3.5 years of age (AlQahtani et al. 2010).

As has already been discussed in Section 6.3, the incremental dentine analysis supports this hypothesis, as $\delta^{15}N$ values from permanent teeth are observed to decrease significantly in sections roughly representing the first three years of life. This is also associated with shifts in $\delta^{13}C$ values, interpreted as increased dietary variability due to weaning (Wright and Schwarcz 1998; Wright and Schwarcz 1999).

6.5.5 Status

As Križna gora produced the largest sample number, and the contents of each grave was known, this site was selected for a pilot investigation into the relationships between carbon and nitrogen isotope ratios, and grave goods. All available long bone collagen and enamel carbonate available from this cemetery have been included in this investigation. From this, themes of status and wealth reflected through diet could be explored. Long bone collagen delta values were used for this investigation, as these isotope ratios reflect the longest average of dietary input and were the least likely to be influenced by seasonality or short-term dietary change, such as breastfeeding or weaning (Parfitt 2002; Hedges et al. 2007; Millard 2000; Fuller et al. 2006). Consequently, because of the very slow collagen turnover rate, delta values representing the average of the diet consumed throughout life could be compared. Carbonate isotope ratios were obtained from permanent tooth enamel, and so only reflect the period of enamel formation. More information regarding the individuals included in this section of the thesis, such as grave goods and sex, can be found in Appendix H, Disk 1.

Individuals buried at this cemetery have been divided based on the fabric of the objects found in their graves: Metal (fibulae, ring jewellery, pins, belt fittings); Metal and non-metal (addition of ceramic vessels and objects); Amber/glass beads (all also had metal and non-metal objects but have been separated); Non-metals (only ceramic vessels); Empty.

Very simple interpretations have been made based on these categories. Individuals buried with metal objects have been associated with a higher wealth/status than those buried with only non-metal objects or with nothing (Križ et al. 2009: 117-121; Frie 2012; Mason 2013). The presence of amber or glass beads has also been used to attribute a higher status because of the skill level required for their manufacture. These individuals buried with beads also contained both ceramic and metal objects, creating elaborate funerary assemblages.

This is only a very simplistic interpretation of individuals, grave goods and isotope ratios. In the past, status was probably influenced by other attributes, including gender, age, skills, and familial ties (Arnold 1995; 1999; Brück 2014). Moreover, the way the deceased was represented in the grave by the living needs to be considered, as objects probably had a symbolic importance beyond that of the material with which they were made (Arnold 1995; 1999; Brück 2014). Consequently, if the relationships between isotope ratios and grave goods were to be investigated in the future, these factors would require more detailed consideration.

Carbon and nitrogen isotope ratios

Carbon and nitrogen isotope ratios from Križna gora have been separated based on grave goods in Tables 6.16 and 6.17, and Figures 6.60 to 6.63. As expected, following the examination of $\delta^{15}N$ values in Section 6.2, very little variation in the spread or distribution could be identified between the different categories. Mean $\delta^{15}N$ values vary between 8.6‰ and 9.1‰, indicating no differences between groups. This is also reflected in the interquartile ranges, which are presented in Table 6.17.

	Mean		Standard deviation	
	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰
Metal (n=3)	-15.6	9.1	0.6	0.2
Metal and non-metal (n=11)	-16.0	8.8	0.4	0.4
Glass +/ Amber (n=3)	-16.3	8.6	0.5	0.3
Non-metal (n=16)	-16.4	9.0	0.4	0.3
Empty (n=1)	-16.9	8.7	0.0	0.0

Table 6.16 Mean $\delta^{13}C$ and $\delta^{15}N$, and standard deviations for different grave good categories

When the $\delta^{13}C$ values are considered, a small variation in the distribution of data is observable in the Metal category, relative to other categories. The mean value of -15.6‰ from the Metal category is also the highest, with mean values ranging from -16.9 to -15.6‰. There is an overall trend of decreasing $\delta^{13}C$ with lower status graves, with the empty grave producing the lowest mean $\delta^{13}C$ value of -16.9‰. This trend has also been reflected in the quartile and interquartile ranges presented in Table 6.16.

When the carbon and nitrogen isotope data are plotted together, as has been done in Figure 6.62, the spread of $\delta^{13}C$ values is visible, with blue squares (individuals buried with metal objects) commonly clustering to the right of the plot, indicating higher $\delta^{13}C$ values.

	Q1	Q3	Q1	Q3	IQR	IQR
	$\delta^{13}C$ ‰	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	$\delta^{15}N$ ‰	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰
Metal (n=3)	-15.3	-15.8	9.1	9	0.5	0.1
Metal and non-metal (n=11)	-15.7	-16.2	8.9	8.5	0.5	0.4
Glass +/ Amber (n=3)	-16	-16.5	8.7	8.4	0.5	0.3
Non-metal (n=16)	-16.1	-16.6	9	8.8	0.5	0.2
Empty (n=1)	-16.9	-16.9	8.7	8.7	0	0

Table 6.17 First and third quartile $\delta^{13}C$ and $\delta^{15}N$ values and interquartile ranges for different grave good categories

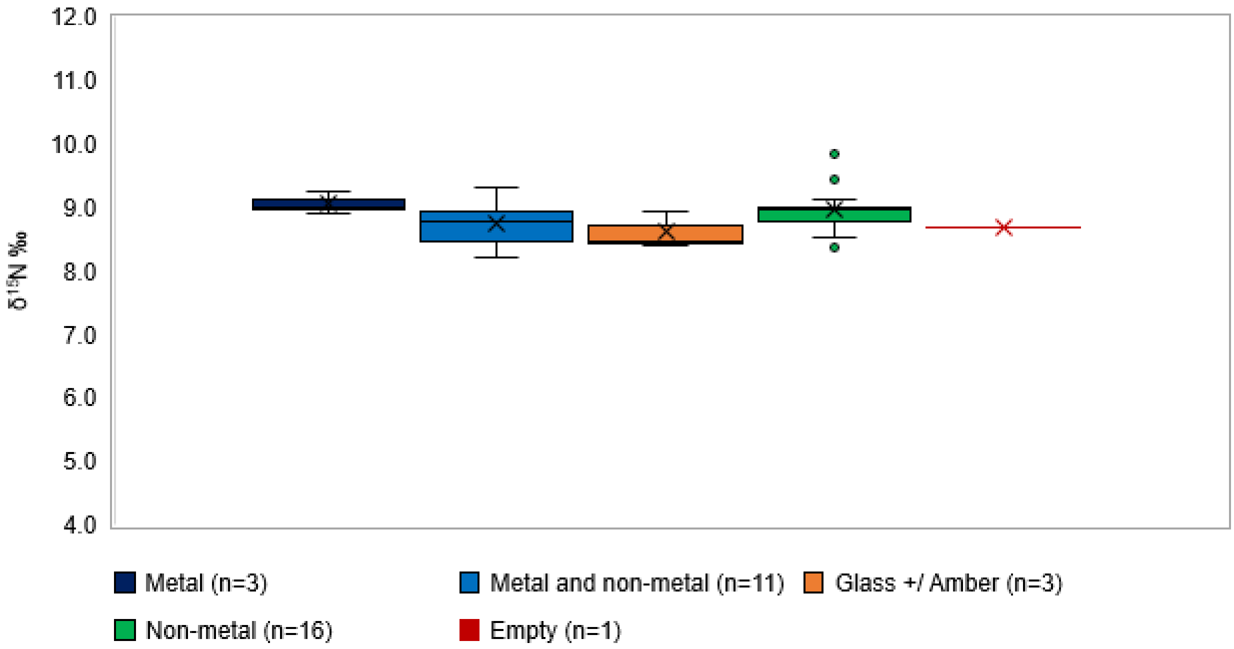

Figure 6.60 A box and whisker plot of $\delta^{15}N$ values for different grave good categories from Križna gora

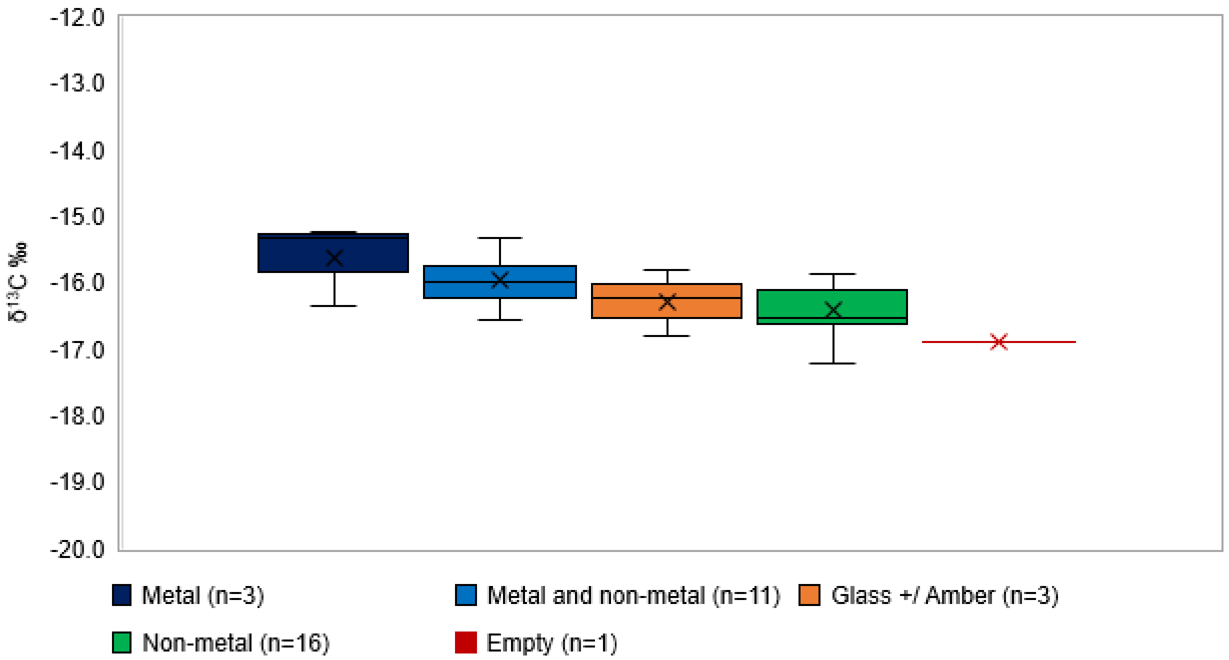

Figure 6.61 A box and whisker plot of $\delta^{13}C$ values for different grave good categories from Križna gora

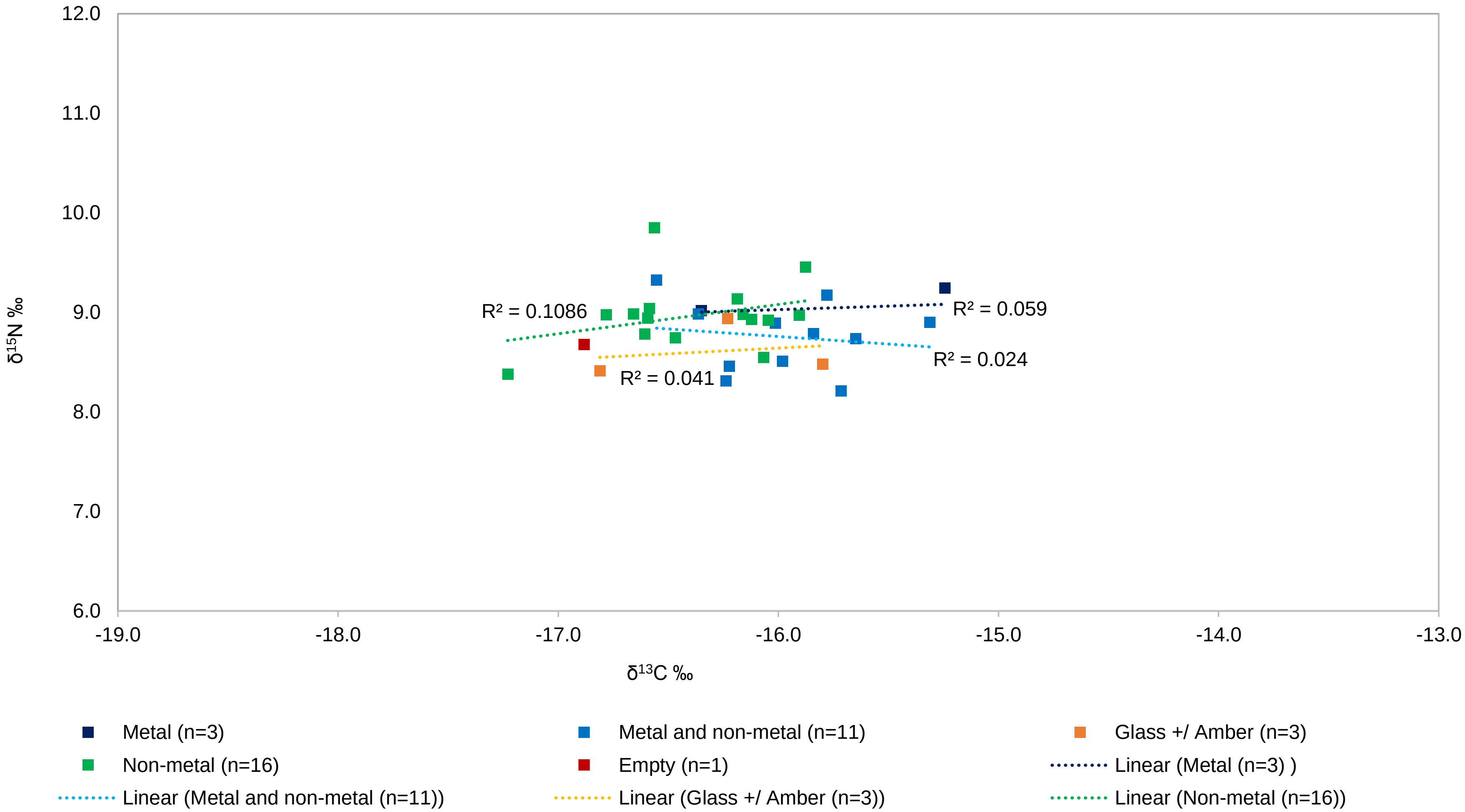

Figure 6.62 A plot of δ^{13}C and δ^{15}N values for different grave good categories from Križna gora

The same individuals have been examined again, using their enamel carbonate isotope ratios. As can be observed in Figure 6.63, the data supports the variation in $\delta^{13}C$ values from long bone collagen. The $\delta^{13}C_{carb}$ values plotting closest to the 100% C4 non-protein component were produced by individuals buried with Metal, Metal and non-metal, and Amber/glass beads (Kellner and Schoeninger 2007; Froehle et al. 2010).

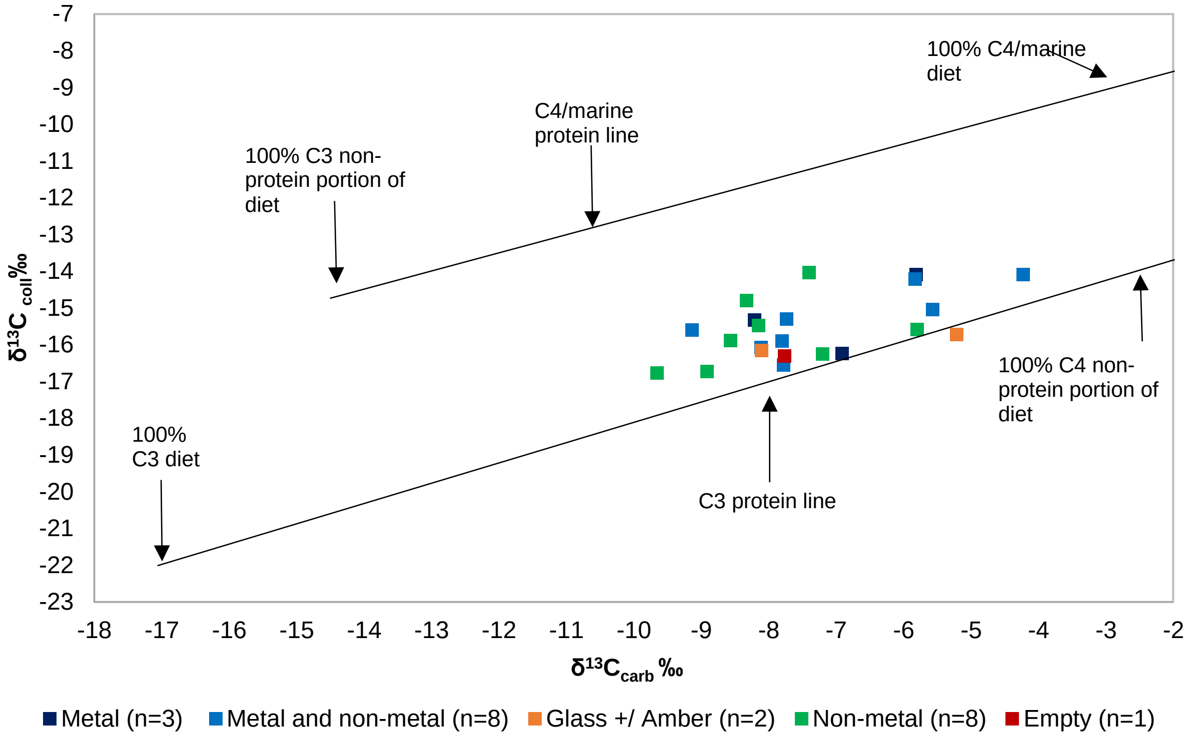

Figure 6.63 A plot of $\delta^{13}C_{coll}$ and $\delta^{13}C_{carb}$ values for different grave good categories, compared with the Froehle et al. (2010) carbon model.

It must be remembered that this is a very biased data set, with uneven sample numbers within each category. This sample can, therefore, not be tested for significant differences using inferential statistics. Consequently, only very cautious interpretations can be made. Taking this into account, the trends reflected by $\delta^{15}N$ values suggest that there was no difference in the animal protein consumed by individuals buried with different grave good assemblages (Hedges and Reynard 2007). The $\delta^{13}C$ values could be reflecting a slight variation in the diet, with individuals buried with metal objects consuming a larger quantity of C4 plants than those buried without metal objects (Tykot 2004; Tieszen 1991; Tafuri et al. 2009). This has also been supported by the $\delta^{13}C_{carb}$ values in Figure 6.63. Subsequently, a tentative interpretation can be made, with those buried in wealthier graves were consuming a larger amount of millet (Kellner and Schoeninger 2007; Froehle et al. 2010). More work, including a more representative sample, would be required to test this hypothesis.

Sex and Status

The relationships between grave goods and isotope ratios have been briefly explored and discussed in this section of the Thesis. These interpretations shall now be viewed with the assistance of the biological context, to test how other aspects of a person's persona, including age and sex, could be influencing this data. When the grave good categories are sub-divided by age (adult versus non-adult) and sex, the tentative interpretations made above become problematic. The main cause for this is found in the sample demography. The Metal category is made of primarily female individuals and the Non-metal category is made up of all males and one non-adult. For this reason, this is a severely unrepresentative data set.

The carbon isotope data is an example of this problem. The carbon isotope ratios have been presented again in Tables 6.18 and 6.19, and Figure 6.64 and 6.66. The distinctions made before, based upon metal versus non-metal objects, can similarly be argued for male and female categories, with $\delta^{13}C$ values produced by female individuals frequently higher than that of males.

	Mean		Standard deviation	
	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰
Metal (Female n=2)	-15.3	9.1	0.0	0.2
Metal (Male n=1)	-16.3	9.0	0.0	0.0
Metal and non-metal (Female n=7)	-15.9	8.6	0.2	0.3
Metal and non-metal (Male =1)	-16.6	9.3	0.0	0.0
Glass +/ Amber (Female n=2)	-16.3	8.4	0.7	0.0
Glass +/ Amber (Non-adult n=1)	-16.2	8.9	0.0	0.0
Non-metal (Male n=11)	-16.4	9.0	0.3	0.3
Non-metal (Non-adult n=2)	-16.9	8.6	0.4	0.3
Empty (Female n=1)	-16.9	8.7	0.0	0.0

Table 6.18 Mean $\delta^{13}C$ and $\delta^{15}N$, and standard deviations for different sex and grave good categories

	Q1	Q3	IQR
	$\delta^{13}C$ ‰	$\delta^{13}C$ ‰	$\delta^{13}C$ ‰
Metal (Female n=2)	-15.1	-15.3	0.2
Metal (Male n=1)	-16.3	-16.3	0.0
Metal and non-metal (Female n=7)	-15.7	-16.1	0.4
Metal and non-metal (Male =1)	-16.6	-16.6	0.0
Glass +/ Amber (Female n=2)	-16.1	-16.6	0.5
Glass +/ Amber (Non-adult n=1)	-16.2	-16.2	0.0
Non-metal (Male n=11)	-16.1	-16.6	0.5
Non-metal (Non-adult n=2)	-16.8	-17.1	0.3
Empty (Female n=1)	-16.9	-16.9	0.0

Table 6.19 First and third quartile $\delta^{13}C$ and $\delta^{15}N$ values and interquartile ranges for different grave good categories

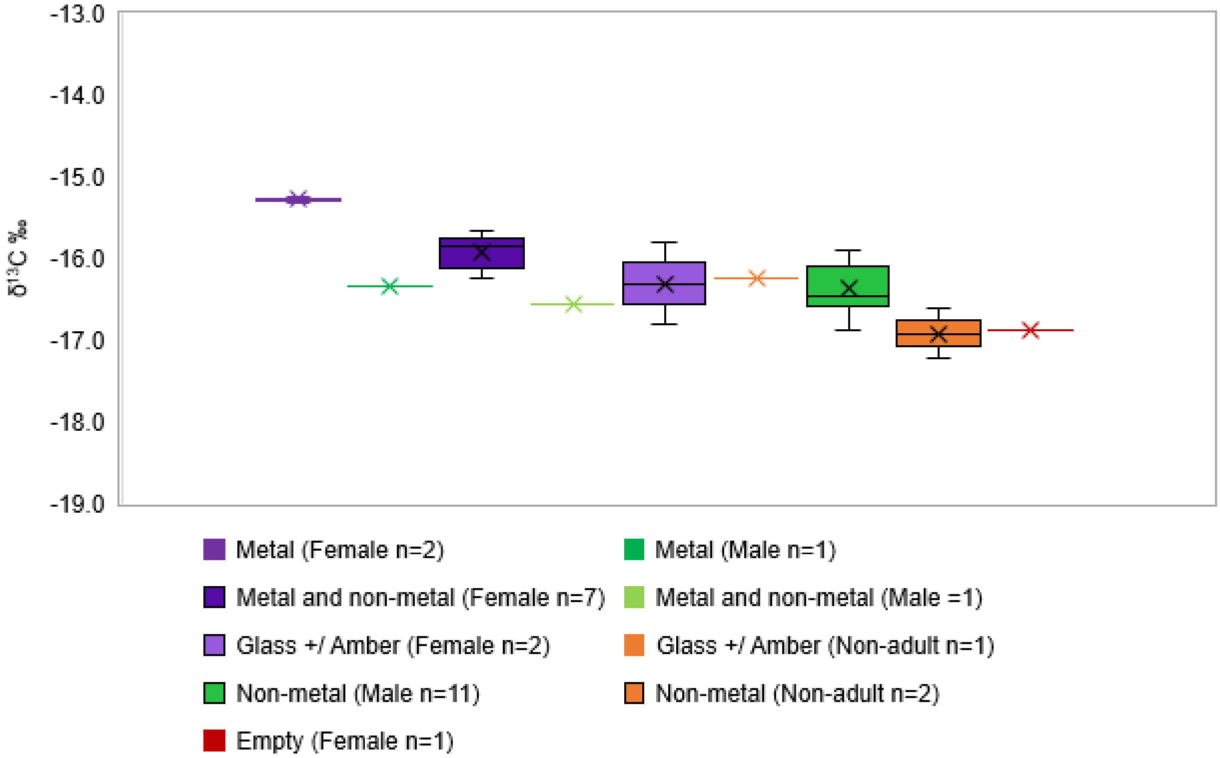

Figure 6.64 A box and whisker plot of $\delta^{13}C$ values for different sex and grave good categories from Križna gora

When the carbon and nitrogen isotope data is plotted together considering the sex of the individuals, there is also a clear distinction between male and females. Furthermore, female individuals frequently plot above males on the x-axis. This trend has also been identified in the enamel carbonate isotope ratios, presented in Figure 6.66, where there appears to be a variation in C4 non-protein consumption based on sex, rather than grave good category (Kellner and Schoeninger 2007; Froehle et al. 2010). Whether the presence or absence of metal objects in their graves is also related to these increased $\delta^{13}C$ values cannot be said as, unfortunately, no female data was available for non-metal graves. However, the one empty grave contained a female individual, who produced one of the lowest $\delta^{13}C$ values (-16.9‰), suggesting comparatively less millet consumption (Tykot 2004; Tieszen 1991; Tafuri et al. 2009).

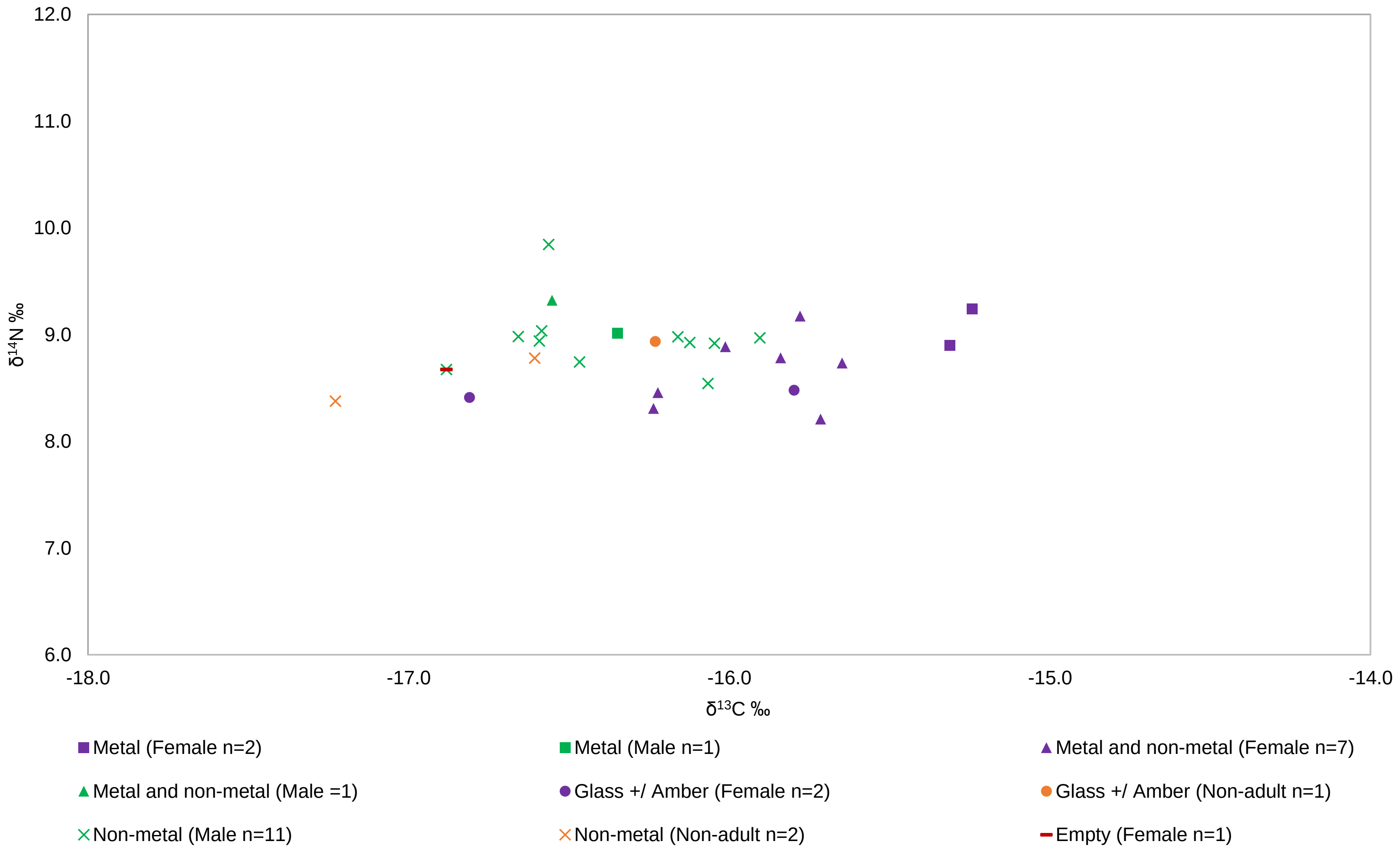

Figure 6.65 A plot of $\delta^{13}C$ and $\delta^{15}N$ values for different sex and grave good categories from Križna gora

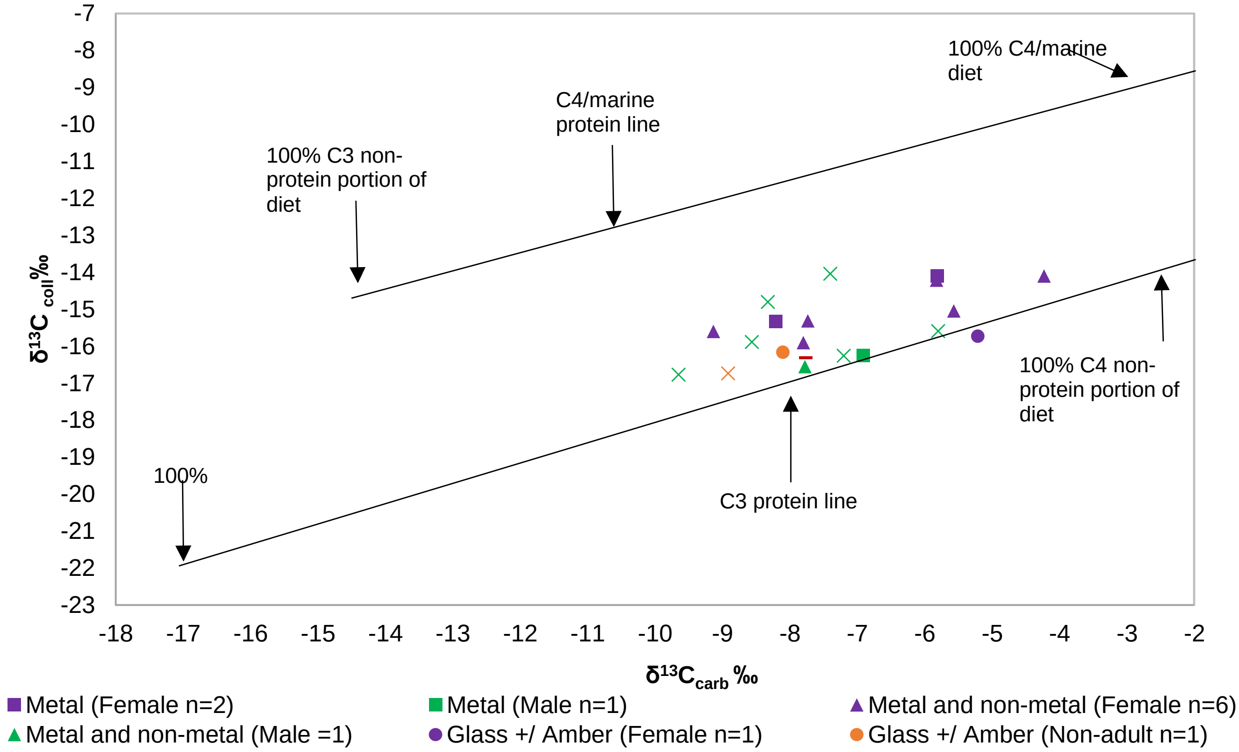

Figure 6.66 A plot of $\delta^{13}C_{coll}$ and $\delta^{13}C_{carb}$ values for different sex and grave good categories, compared with the Froehle et al. (2010) carbon model.

Overview of stable isotope ratios and status

Initially, the stable carbon isotope data appeared related to the objects found in the graves. There was evidence to suggest that individuals with wealthier grave assemblages (including a mix of metal, ceramic and/or amber/glass objects) were frequently producing higher $\delta^{13}C$ values. This would suggest that C4 plants (millet) played a larger role in the diet of these individuals, relative to those buried in less wealthy or lower status graves. However, it has also been argued that the heavily biased nature of this sample has had a significant impact on these trends. There is an unequal spread in the numbers of males and females within grave good based categories. For instance, the Metal category is predominantly made up of females, whereas the Non-metal category contains no females. Consequently, it is not possible to interpret how much of an influence the sex of the deceased is having on this sample. Any differences observed in the isotope ratios of object-based groups could, therefore, be a relationship between isotope ratios and grave goods, or sex, or even a combination of both. The evidence, discussed in Sections 6.5.2 and 8.8.2, does indicate that sex is a cause for heterogeneity in stable isotope data.

To further elucidate the cause of isotopic variation related to identity (gender, wealth and status) in this study area, more samples reflecting more representative categories based on sex and grave goods are necessary. Nevertheless, this isotopic variability in relation to sex, grave goods, or both, is evidence of dietary heterogeneity within this data set, which addresses the first aim of this study.

6.6 Summary of carbon and nitrogen isotope analysis

The application of a suite of isotopic techniques, on multiple skeletal elements, has allowed for the investigation of isotopic variability throughout the lifespan of a single individual. This has been most obviously displayed using incremental dentine analysis, where the isotopic composition of childhood diet was seen to alter throughout the course of dental development.

By comparing the carbon ratios obtained from then dentine collagen and enamel carbonate, it was possible to identify subtle variations in the composition of people's diet in terms of the relative importance of non-protein dietary components, with some individuals appearing to consume higher quantities of C4 plants than others (Kellner and Schoeninger 2007; Froehle et al. 2010). The consideration of $\Delta^{13}C_{coll\text{-}carb}$ values calculated from the carbon isotope ratios from tooth enamel and dentine collagen was also a source of evidence to suggest a high intake of C4 plants (Ambrose 1997; Finucane et al. 2006; Loftus and Sealy 2012)

Throughout this chapter, it has been observed that a multi-scalar approach, with the application of methods with an array of different resolutions, has resulted in a more advanced understanding of paleodiet in prehistoric Slovenia and eastern Croatia. When the carbon and nitrogen isotope ratios from the bulk collagen of apex dentine, rib and long bone samples were initially examined, all individuals included in the ENTRANS data set fall within a relatively tight range of delta values. Additionally, the regular occurrence of $\delta^{13}C$ and $\delta^{15}N$ values from each skeletal element plotting in similar positions have indicated that there was little variation in the isotopic composition of diet between age groups or the two sexes. Moreover, no dietary distinctions could be made that would relate to social status or structure. Overall, the individuals inhabiting this geographical region during the Bronze and Early Iron Age appear to have been subsisting on a very homogenous diet of terrestrial protein and a mix of C3 and C4 plants, most likely millet (Tykot 2004; Lightfoot et al. 2014b).

When other data sets and higher resolution methods are employed, more subtle variations in the isotopic composition of diet can be teased out, which suggests that the bulk isotope ratios are obscuring a more complex situation. Incremental dentine analysis has revealed that the quantities of millet consumed may have varied periodically, but also that the consistency of diet and the routing of macronutrients probably played a role in isotopic variation. Similarly, the use of enamel carbonate in conjunction with dentine collagen has provided evidence for diversity in the composition of the whole diet between some individuals. When modelled, individuals from within a community appear to be consuming an inconsistent mix of C3 and C4 protein. Moreover, some individuals, such as 3043 and the remains of the vessel from the same grave, have produced $\delta^{13}C_{carb}$ values that show a differentiation between non-protein carbon sources. Further still, this study has shown that enamel carbonate values broadly model in a similar way to that of bone apatite values, and therefore can be used to investigate the whole diet.

Overall, even though the foodstuffs consumed by different members of the population do not appear to have varied significantly, there are hints that the composition of diet did not always stay the same. From the ENTRANS data set, it can be argued that those inhabiting this geographical region were subsisting on a relatively similar diet, and rather than seeing a separation in C3 versus C4 consumers, subtle differences have been identified in the relative importance of each plant type. This may have been related to differential access to protein and carbohydrates because of social standing, seasonality and so on.

Without the combined use of higher resolution methods and the examination of multiple tissue types, these subtle differences would not have been visible.

Chapter 7 Case study: a carbon and nitrogen isotopic investigation of a case of probable infantile scurvy using incremental sampling of deciduous dentine

This chapter provides a case study combining contextual, osteological and isotopic data to produce a biography for a single individual from the ENTRANS project: Infant 1 from Zagorje ob Savi (750-400 cal. BC). This case study has been used to illustrate the advantages of bringing together multiple strands of evidence to create more informed interpretations regarding life and death in prehistory. This case study also stresses the importance of context when interpreting stable carbon and nitrogen isotope data.

The analysis of stable carbon and nitrogen isotopes in human bone and dentine collagen has become commonplace for the investigation of diet in the past (See Chapter 3). More recently, the investigation of $\delta^{15}N$ values has been used for the investigation of health status, as this stable isotope ratio is not only reflective of diet, but of an individual's nitrogen balance (Fuller et al. 2004 ; Fuller et al. 2005; Beaumont et al. 2013b; Beaumont et al. 2015). This balance is affected, not only by dietary nitrogen, but also by metabolic processes, such as growth, malnourishment, and illness (Mekota et al. 2009; Waters-Rist and Katzenberg 2010). This case study from Iron Age Slovenia aims to investigate change in nitrogen balance over time in the forming tissues of an infant with skeletal lesions consistent with scurvy (vitamin C deficiency).

7.1 Infant 1, Zagorje ob Savi

The individual presented in this chapter was excavated from the Slovenian, Early Iron Age cemetery site of Zagorje ob Savi (Draksler 2011; Murko 2011). Six skeletons were recovered from this site, though the cemetery site itself was probably larger and has not been fully excavated (see Section2.2 (Murko 2011)). Carbon and nitrogen stable isotopic analysis was carried out on rib fragments from three adults. A bulk rib sample was taken from Infant 1, in addition to incremental dentine sampling. The study has also included bulk collagen samples from three cattle, two pigs and a deer. These bones were excavated from the graves of the individuals that make up this data set, and so are believed to form a contemporary baseline of carbon and nitrogen isotope ratios for the area.

Infant 1 was aged c. 7.5 months old at the time of death, based on dental development (AlQahtani 2010). Due to the biological age of the individual, the remains were not assessed for sex. The palaeopathological analysis was undertaken through macroscopic observation of the bone following standard observation and recording methods (Ortner and Ericksen 1997; Ortner et al. 2001; Brickley and Ives 2006; Mays 2008a).

The preparation and measurement of collagen samples have been explained in Chapter 3. Incremental dentine samples were taken from the first deciduous incisor of the infant remains following Beaumont et al (2013). An approximate age was attributed to each dentine section by dividing the length of time required for the enamel crown to form (using the dental atlas by AlQahtani et al. (2010) by the number of increments sampled. The approximate ages attributed to increments represents a midpoint of tooth development of +/- 0.5 years and do not account for the lag between changing diet and the incorporation of isotope signals into forming tissues (Beaumont et al. 2013b). Consequently, relationships between age and isotope ratios have not been explored in great depth. Instead, results are discussed in terms of general trends.

7.2 Results

7.2.1 Palaeopathological analysis

Some of the pathological lesions described here are depicted in Figure 7.1. The skeletal remains of Infant 1 exhibited a high prevalence of abnormal porosity. In the cranium, this was noted in the roof of the orbits and diffusely across the endo- and ecto-cranial surfaces of the frontal and parietal bones. This was associated with layers of porous and compact new bone in the orbits, and plaques of compact bone on the endocrinal surface of the parietals and frontal bone. The basilar portion of the occipital bone, the petrous bone, the hard palate and external areas of the maxilla (right), extending away from the alveolar bone towards the maxillary sinus, also exhibited extensive abnormal porosity.

Diffuse porosity was also observed across the ribs and the diaphysis of the right tibia and fibula (the left being absent). It was also present bilaterally across the diaphyses of the femora and humeri. This was also associated with diffuse plaques of woven and compact across the diaphyses of the right tibia, both humeri and both femora. Compact and striated bone was noted along the linea aspera of the right femur. The greater wings of the sphenoid and both scapulae were absent.

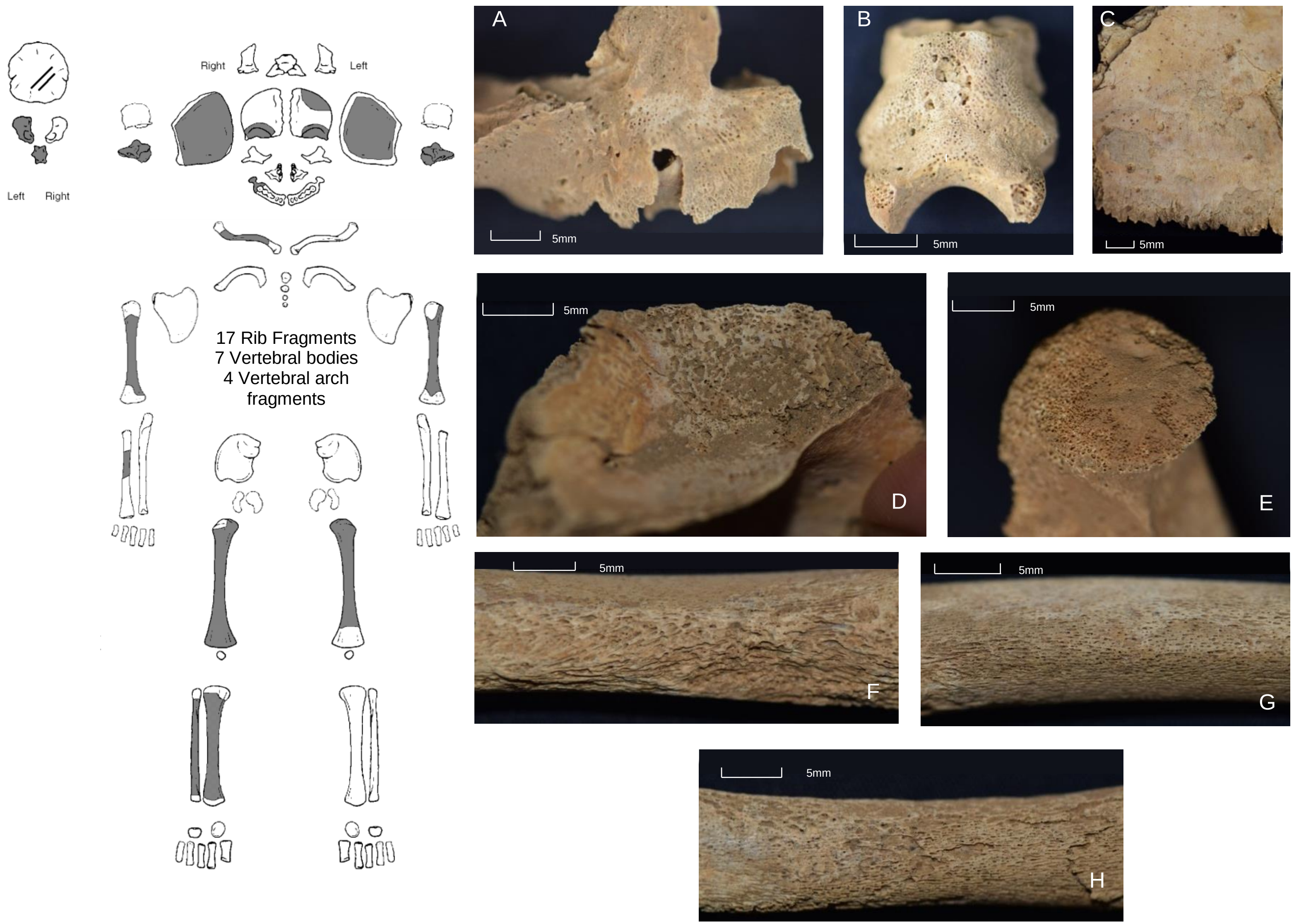

Figure 7.1. **Left:** Inventory of Infant 1 skeletal remains; **Right: A**. Right maxilla fragment showing porosity around maxillary sinus; **B**. Basilar portion with abnormal porosity; **C.** Endo-cranial surface of parietal bone with plaques of compact bone; **D.** Right orbit with layers of porous compact bone; **E.** Left proximal femur showing normal, unfused joint surface and no deformation of shape; **F**. Posterior right femur with porous compact bone on and around the linea aspera; **G**. Anterior right tibia showing plaque of porous woven and compact bone on top of original cortical surface; **H**. Posterior right humerus showing plaque of porous woven and compact bone on top of original cortical surface.

7.2.2 Carbon and nitrogen Isotopes

Bulk rib samples of individuals buried at Zagorje ob Savi

The results of bulk rib collagen carbon and nitrogen stable isotope analysis from four individuals buried at Zagorje ob Savi has been presented in Figure 7.2 and Table 7.1. All samples fell within the accepted C:N ratio and >1 % collagen yield, indicating good collagen preservation (Van-Klinken 1999). The rib collagen of the infant buried at this cemetery has significantly higher $\delta^{13}C$ (+2.9‰) and $\delta^{15}N$ (+3‰) values when compared to the isotopic ratios of the adults.

Adult rib isotope ratios	*$\delta^{13}C$ ‰*	*$\delta^{15}N$‰*	*C:N*
Middle adult male	-14.8	8.6	3.21
Middle adult female	-15.2	8.9	3.19
Middle adult female	-14.4	9	3.18
Infant rib	-11.9	11.8	3.15
Infant dentine (average of whole tooth)	-12.1	12	3.18

Table 7.1. Bulk carbon and nitrogen ratios from adult rib collagen, Zagorje ob Savi

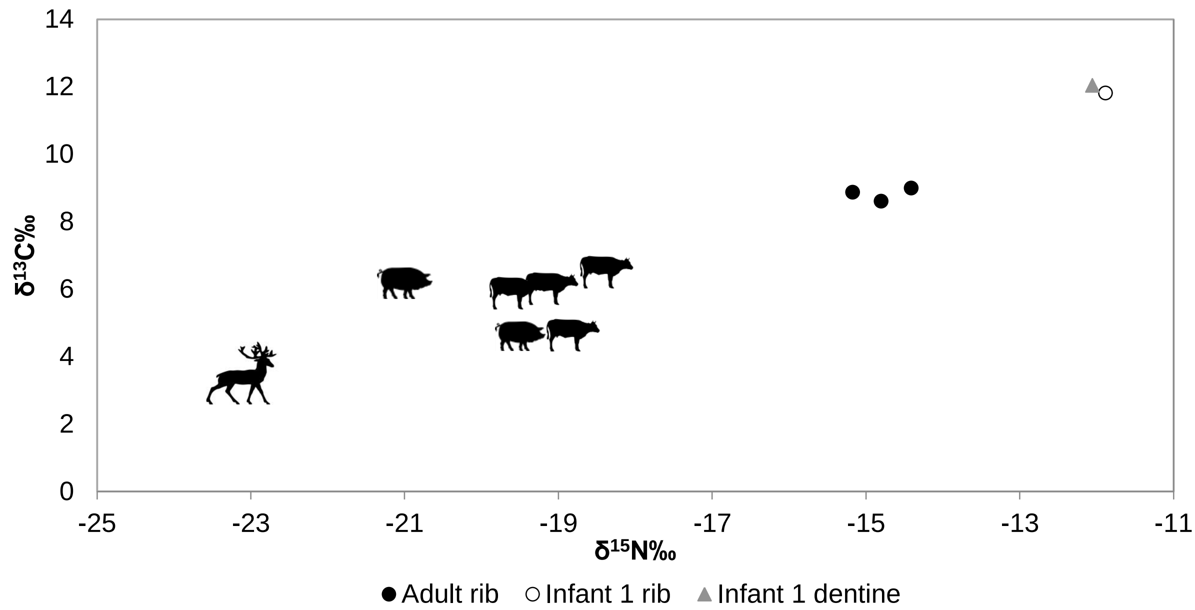

Figure 7.2.A plot of carbon and nitrogen isotope ratios obtained from the remains of individuals buried at Zagorje ob Savi. Samples include adult rib collagen (3) and of the rib and dentine collagen extracted from Infant 1(mean value of all dentine increments). The plot also includes carbon and nitrogen isotope ratios of animal bone collagen sourced from the same graves as the human remains.

Incremental dentine analysis of a first deciduous incisor, Infant 1

The results of incremental dentine analysis are shown in Table 7.2 and Figure 7.3. Figure 7.3 displays an increase in both $\delta^{13}C$ (+1.2‰) and $\delta^{15}N$ (+2.3‰) values throughout the development of the tooth root. In comparison to $\delta^{13}C$ values, $\delta^{15}N$ values are observed to increase more rapidly and by a higher magnitude, most notably after approximately 10.5 months post conception ($\delta^{15}N$ = +1.7‰; $\delta^{13}C$ = + 0.8‰).

Dentine increment	*$\delta^{13}C$ ‰*	*$\delta^{15}N$ ‰*	**C:N**
1 (crown)	-12.6	11.2	3.2
2	-12.4	11.4	3.2
3	-12.2	11.6	3.2
4	-12.1	11.8	3.2
5	-12.0	12.1	3.2
6	-11.7	12.7	3.2
7 (apex)	-11.3	13.5	3.2

Table 7.2. Carbon and nitrogen isotope ratios from dentine increments of the first deciduous incisor, Infant 1, Zagorje ob Savi.

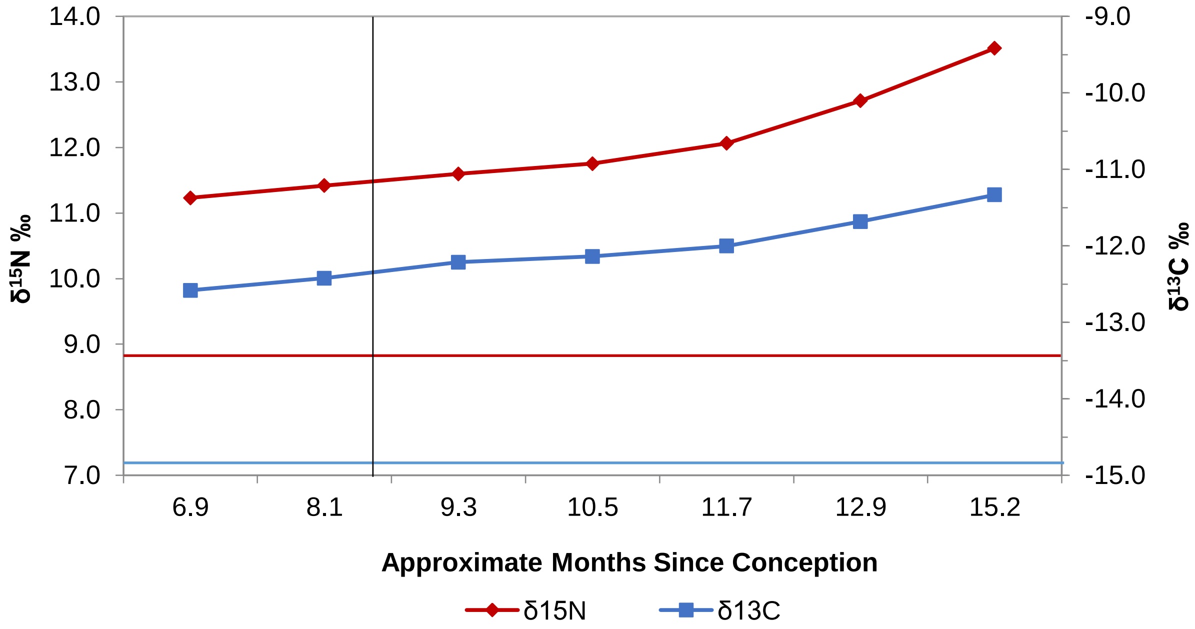

Figure 7.3. A plot of carbon and nitrogen isotope ratios of incremental dentine sections, from the first deciduous incisor, Infant 1, Zagorje ob Savi. The red and blue trend lines represent changing metabolic and dietary conditions from pre-birth to around the time of death, as reflected through isotopic variation. The black line represents the approximate time of birth to indicate dentine formation in-utero. The red line represents the mean adult rib $\delta^{15}N$ value of 8.8‰ and the blue line the mean adult rib $\delta^{13}C$ value of -14.8‰

7.3 Discussion

7.3.1 Pathological lesions

Widespread porosity and sub-periosteal bone formation are known to be associated with several pathological conditions. These include inflammation, non-specific infection and metabolic disease, such as haemolytic (caused by the premature destruction of red blood cells) or megaloblastic (deficient in vitamin B_{12} and folic acid) anaemia, rickets (childhood vitamin D deficiency) and scurvy (vitamin C deficiency) (Ortner and Ericksen 1997; Ortner and Mays 1998; Ortner et al. 2001; Brickley and Ives 2006; Mays 2008a; Walker et al. 2009)

Megaloblastic and haemolytic anaemias are believed to result in porotic hyperostosis in the cranial vault as well as cribra orbitalia in the orbital roof due to the expansion of the diploë (Walker et al. 2009). This occurs when the hematopoietic marrow is stimulated to increase red blood cell production at the expense of the outer and inner table of the stull (Walker et al. 2009).

Non-specific infections and inflammation involving the periosteum, for example in the orbital roof, can also result in porous bone (Lewis 2004). Sub-periosteal reaction due to infection and/or inflammation can similarly result in porous bone growth across the long bones (Weston 2008).

Rickets results from the inability to adequately mineralise the bone due to the lack of vitamin D during growth. This produces pores in dry bone as the inadequately mineralised osteoid that once filled these spaces does not survive the burial environment (Ortner and Mays 1998; Mays et al. 2006). This is commonly associated with the deformation of long bones and sternal rib ends, as well as a roughened bone surface beneath epiphyseal joint plates. As some of these deformities are related to weight bearing whilst crawling or walking, they would not be visible in the current case. Bony changes have been recognised in infants as young as 3 months, affecting the ribs, orbital roof, cranial vault, and growth plates (Ortner and Mays 1998). A pattern of struts and slits across major long bones were also observed on radiographs by Ortner and Mays (1998), showing that rickets is diagnosable in infants who have not yet begun walking.

The lesions consistent with chronic scurvy present in the orbital roof as layers of compact bone, which form during different stages of recovery and healing (Brickley and Ives 2006; Mays 2008a; Walker et al. 2009). This is triggered following the reintroduction of vitamin C, when the weakened connective tissues and vessels in the orbits haemorrhage, thought to be due to minor trauma inflicted by the movement of the ocular muscles (Mays 2008a; Walker et al. 2009). Porous lesions also develop across the skeleton due to the increased formation of blood vessels that penetrate the bone (Brickley and Ives 2006). These vessels are symptomatically fragile due to weak collagen formation, resulting in continued haemorrhaging.

Through the observation of reactive bone formation and abnormal porosity – defined following Ortner et al (2001: 344) as a "…localised condition in which fine holes, typically less than 1mm in diameter, penetrate a compact bone surface" – at specific locations, including the posterior maxilla, basilar portion, in the orbits and lower limb bones around muscle attachment sites, the presence of scurvy may be identified (Ortner et al. 2001; Mays 2008a; Moore and Koon 2017).

In the case of Infant 1 from Zagorje ob Savi, although the greater wings of the sphenoid and scapulae were absent in this case, Ortner et al (2001) have argued that scurvy can affect the skeleton without involving the greater wing of the sphenoid and, additionally, Brickley and Ives (2006) have cautioned against the over-dependence on one skeletal element for the diagnosis of pathology. The absence of hyperplasia of the diploë or in the medullary cavities of the long bones suggests these lesions were not the result of anaemia (Ortner et al. 2001; Brickley and Ives 2006). The lesions are also not consistent with those of rickets – no evidence of deformity was noted in the long bones or ribs and the surfaces of the epiphyses were normal. There was also no evidence of bone struts. The new bone growth identified across the endocranial surface and long bones were laid down upon the existing cortical surface, a feature which has been previously linked to haemorrhage resulting from scurvy (Lewis 2004; Mays 2008a). Haemorrhaging from capillaries would have led to localised areas of inflammation and porosity while bleeding close to the periosteum would have triggered the formation of new bone, as seen across many of the skeletal elements (Mays 2008b: 223). The plaques of compact bone identified in the endocranial surface of the skull, in conjunction with the layers of compact bone observed within the orbits of Infant 1, suggest that there were phases of recovery and healing, as new bone could only have been laid down during a recovery phase (Brickley and Ives 2006).

The pathological lesions consistent with scurvy have been argued to be more common in the skeletal remains of young children, due to the high demands of rapid growth (Ortner and Ericksen 1997; Ortner et al. 1999). As the child develops, poor collagen formation leads to arrested osteoblastic activity and the collagenous bone matrix does not ossify. Haemorrhaging then encourages the formation of an increased number of vessels, which penetrate the bone surface. These vessels are commonly poorly formed and break easily (Brickley and Ives 2006).

In addition to abnormal porosity, the occurrence of reactive bone formation across the parietals and also across the long bones has been observed as relatively rare in association with abnormal porosity; it has been suggested that this indicates a more severe expression of bleeding from vessels and has been linked to the probable stripping of the periosteum from the bone (Ortner et al. 2001; Brickley and Ives 2006).

It is reported that the clinical symptoms associated with scurvy become identifiable after around 2-3 months of deficient vitamin C intake (Larralde et al. 2007). If this is the case, it is likely that Infant 1 suffered from a chronic deficiency in vitamin C. The first months of life are crucial for development and an infant is expected to double in size and the total brain weight to triple (Boué et al. 2016). This growth is normally supported through breastmilk, which provides sufficient nutrition for healthy growth and development. However, if nutritional requirements are not met, infants are more susceptible to infection and disease due to an under-developed immune system (Nguyen et al. 2013). A deficiency in vitamin C not only leads to the poor formation of collagen (and therefore flawed osteoid formation) but can also inhibit the absorption of iron from the small intestine, leading to iron deficient anaemia (Brickley and Ives 2006).

It is known from modern-day diagnosed cases of infantile scurvy that abnormal collagen formation can lead to bleeding in the skin, mucous membranes, muscles, and gastrointestinal tract and around the joints (Jackson and Park 1935; Larralde et al. 2007). Individuals suffering from scurvy may also have difficulties with coagulation of the blood, which can exacerbate the problem and lead to the complications with healing wounds (Larralde et al. 2007). Clinical symptoms include fatigue, irritability, and delayed or stunted development. Haemorrhagic skin lesions are common, and haemorrhaging from the eyelids and gums has also been described (Larralde et al. 2007).

Swelling of the lower extremities has been observed, potentially with multiple causalities, including leaking capillaries and soft tissue haemorrhage (Larralde et al. 2007). Intense joint pain and muscle weakness, especially in the lower limbs, leads to children suffering from scurvy to have very little movement and a tendency for them to lie in an abduct or ‘frog-like’ position (Larralde et al. 2007). Therefore, the probable Zagorje ob Savi case of infantile scurvy would have resulted in particularly visible symptoms.

It is important to note, however, that a malnourished individual could suffer from more than one disease or condition. The occurrence of one can weaken the immune system, causing the individual to become more susceptible to other illnesses. The individual presented here may have been additionally affected by any of the above alternative disorders, including rickets or anaemia. The observation of widespread and bi-lateral porosity and porous plaques of new bone on top of the original cortical surface, in areas of the post-cranial skeleton not associated with muscles or muscle movement, is suggestive of another systemic non-specific condition.

7.3.2 Carbon and nitrogen isotopes

Isotopically, there is a clear difference between the bone (and dentine) collagen of Infant 1 and the three contemporaneous adults from Zagorje ob Savi (Figure 7.2 and 7.3). High nitrogen isotope ratios have been linked to breastfeeding practices in previous isotopic studies (Millard 2000; Fuller et al. 2006; Jay et al. 2008). As demonstrated by the model shown in Figure 7.4 (blue line), breastfeeding has been shown to result in a rapid trophic level shift in the $\delta^{15}N$ of infant soft tissues, with increasing isotope values of up to 2-3‰ (Fuller et al. 2006). This occurs as the infant ingests the proteins of their mother via breastmilk, which results in additional isotopic fractionation in comparison to the mother. This increased $\delta^{15}N$ subsequently drops gradually to a value similar to the mother throughout the process of weaning (introduction of solid foods commonly combined with continued nursing) and the cessation of breastfeeding, provided the mother and child are sharing a similar diet (Millard 2000; Fuller et al. 2006; Jay et al. 2008).

Given the age of Infant 1 (c.7.5 months), it is possible that this significantly higher $\delta^{15}N$ value is linked to breastfeeding. However, more recent studies into archaeological dentine and modern hair and breast milk samples have suggested that high $\delta^{15}N$ values in infants may not be solely the result of the ingestion of breastmilk (de Luca et al. 2012; Romek et al. 2013; Beaumont et al. 2015). Beaumont and colleagues have shown that the nitrogen isotope ratios of children are more complex and that high $\delta^{15}N$ values can also be linked to changes in metabolism, maternal health, or a disruption to the nitrogen balance (Beaumont et al. 2015; Reynard and Tuross 2015). As demonstrated in Figure 7.3, $\delta^{15}N$ values for Infant 1 steadily increase over time, rather than abruptly after birth – a trend that may have indicated breastfeeding (Figure 7.4). Additionally, they do not reflect the profiles seen in Beaumont et al (2013; 2015), where “survivors” of childhood have characteristically flat nitrogen isotope profiles. Moreover, although $\delta^{13}C$ values do alter throughout the profile, they do not change as rapidly or as greatly as $\delta^{15}N$ values, which could support the hypothesis that $\delta^{15}N$ values are reflecting a metabolic change, rather than a dietary one.

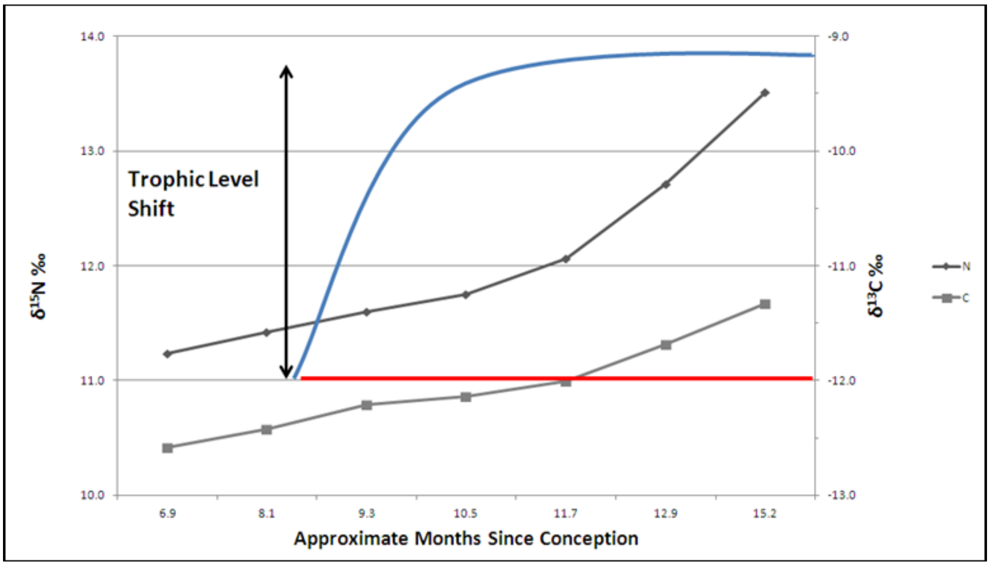

Figure 7.4. A model of change in nitrogen isotope ratios over time, related to breastfeeding, as reported from modern soft tissues of nursing infants (Fuller et al. 2006). Adapted from Millard (2000). The blue line represents an abrupt increase in $\delta^{15}N$ values related to the onset of breastfeeding. The red line represents the lack of change noted in $\delta^{13}C$ values, unless the diet of the mother changes to incorporate/reduce marine or C4 based foods. The incremental dentine data obtained from Infant 1 is presented in grey for comparison.

To understand more fully the comparatively high $\delta^{15}N$ values (and comparatively smaller corresponding increase in $\delta^{13}C$ values) from the bones and teeth of Infant 1, it is vital to consider the probable diagnosis of chronic scurvy. In modern times the identification of infantile scurvy is exceptionally rare, as breastmilk contains enough vitamin C to support new-borns (Larralde et al. 2007). Increased $\delta^{15}N$ values have already been linked to malnutrition on several occasions (Hobson et al. 1993; Fuller et al. 2005; Mekota et al. 2009; Beaumont et al. 2015). When the body does not receive the required dietary nitrogen (e.g. needed for protein synthesis), the body instead obtains it from bodily tissues. This breakdown of body tissues, known as catabolism, causes isotopic fractionation as molecules containing the lighter isotope, ^{14}N, break down more readily. This results in an enrichment of the heavier isotope, ^{15}N, in the tissues that are then sampled for isotopic analyses (Hobson et al. 1993; Fuller et al. 2005; Mekota et al. 2009; Beaumont et al. 2015).

The following presents some potential scenarios, which could explain the variation in carbon and nitrogen isotope ratios observed between Infant 1 and the associated adults. Firstly, the weakly co-varying carbon and nitrogen isotope values suggest a possible change in diet over time. The high $\delta^{13}C$ values ranging between -12.6‰ and -11.3‰ indicate either a substantial marine or C4 dietary input and are considerably higher than that of the adult isotope ratios

(+3 - 4‰). The ingestion of marine food is particularly unlikely given the location of the cemetery (see Chapter 2), but also, as discussed further in Chapter 6, there is no isotopic evidence (to date) for the consumption of marine food during prehistory in Slovenia (Nicholls and Koon 2016). There is, however, substantial evidence for the consumption of C4 plants in the wider area, namely millet (Dular and Tecco-Hvala 2007: 206-212; Lightfoot et al. 2014b; Papeša et al. 2015; Nicholls and Koon 2016: 207, 209; Reed and Drnić 2016). The adult individuals buried at Zagorje ob Savi also provide evidence of C4 plant consumption. It is posited, then, that a substantial amount of the dietary carbon for Infant 1 was obtained from millet, and that the amount of millet ingested increased with time, as indicated by the increase in $\delta^{13}C$ values throughout the development of the tooth.

This is not to say that the infant was ingesting millet as a grain—given the age of the individual, it is unlikely that they were eating solids—but that the C4 isotope signature was being transmitted indirectly into their diet through another route. This signal may have initially been introduced to the foetus in-utero via the mother. If Infant 1 was nursing, the gradually increasing $\delta^{13}C$ values could indicate a change in the mother's diet whilst breastfeeding, though the diagnosis of probable scurvy still brings this interpretation into question, as a breastfeeding infant should not suffer from severe malnutrition, unless the mother also suffered from scurvy (Jackson and Park 1935; Bates and Prentice 1994).

In Section 6.3, it was noted that the $\delta^{13}C$ values of Infant 1 were noticeably higher (+1.5 - 2‰) than that of other dentine increments obtained from individuals buried at other cemeteries (Križna gora, Obrežje and Sv Križ), reflecting a similar period of development (first year of life). The dentine $\delta^{13}C$ value for Infant 1 was also the highest carbon isotope ratio for the whole ENTRANS data set. This suggests the diet of this infant was significantly different from other adults and children in terms of the quantity of C4 based dietary carbon ingested.

One possibility that could account for both the high $\delta^{13}C$ and $\delta^{14}N$ values (relative to adult rib collagen) is that they were the result of the ingestion of animal milk, as a replacement for breastmilk, where the animal had been foddered on millet. It is recognised that the ingestion of unmodified animal milk, for example, bovine milk, by young infants (c. <12 months) is particularly unhealthy (Fleischer Michaelsen et al. 2000; Binns et al. 2007). Animal milk as a substitute for breastfeeding is a potential cause for this infant's illness, as cow's milk and goat's milk are deficient in vital nutrients, including vitamin C. The consumption of cow's milk by infants under the age of 12 months can cause blood loss from the gastrointestinal tract, also leading to iron deficiency and anaemia (Binns et al. 2007; Wijndaele et al. 2009; Griebler et al. 2016).

Another scenario can be interpreted from the earliest incremental dentine sections. The pre-birth dentine $\delta^{15}N$ values are significantly higher than that of the adult rib values (c.+2.4‰ between the mean adult rib $\delta^{15}N$ value and the first dentine increment of Infant 1). These $\delta^{15}N$ values may be indicative of the nitrogen balance of the mother, who may also have been physiologically stressed (Fuller et al. 2005; Mekota et al. 2009; Beaumont et al. 2015). The unborn foetus would have obtained its nutrients directly from the mother across the placenta, thereby transferring the maternal isotope values into the forming tissues of the unborn baby. The $\delta^{15}N$ values would therefore roughly reflect the isotopic composition of the mother's diet during pregnancy, but also their metabolic status (Beaumont et al. 2015). The relatively high $\delta^{15}N$ values exhibited in the incremental dentine of Infant 1 may indicate maternal physiological stress during pregnancy (Fuller et al. 2005; Beaumont et al. 2015).This interpretation should be treated with caution. The infant was buried in an individual grave and even had they been buried with an adult, it would be impossible to relate individuals without the use of aDNA. Therefore, it was not possible to identify the remains of the mother (who may have survived) for osteological or isotopic analyses. However, the hair of modern pregnant women has shown that maternal stress during pregnancy, such as morning sickness, increases nitrogen isotope ratios (Fuller et al. 2005). If the mother of Infant 1 was severely malnourished, this would have had a negative impact on their child. During periods of short-term stress, pregnant or lactating women will generally route necessary nutrients to the foetus or into producing milk at their own expense (Bates and Prentice 1994). If the woman is severely malnourished, this would not be possible. This has been demonstrated in rare clinical cases of congenital scurvy, where it is likely that the mother herself suffered from the disease whilst pregnant or lactating (Jackson and Park 1935).

The diagnosis of scurvy supports the hypothesis that this infant was not successfully breastfed. It is known that breast milk usually contains enough nutrition for an infant to thrive without additions to their diet, including water, for the first 6 months. The World Health Organisation (WHO) recommends that an infant is exclusively breastfed for the first 6 months, and then for complementary foods to be ingested in addition to breastmilk for the first 2 years (Dewey 2005). It would, therefore, be unusual to find an infant of this age (7.5 months), with such severe nutritional deficiencies, if they had been successfully breastfed. Evidence for breastfeeding during the Late Bronze Age and Early Iron Age within the ENTRANS study area has been discussed in Section 6.5.4, using enamel carbonate analysis. Further evidence shall be explored using oxygen isotope analysis in Chapter 8.

7.4 Conclusion

The infant presented here suffered from severe and chronic malnutrition, probably scurvy. This has been supported by both the stable isotope data and osteological observations. $\delta^{15}N$ values continue to rise throughout the development of the tooth, indicating a sustained negative nitrogen balance, while the pathological lesions on the skeleton indicate a prolonged illness linked to malnutrition.

In the past, high nitrogen isotope values obtained from the tissues of infants have been linked to breastfeeding practices. The example presented here offers an alternative interpretation. This case study supports the argument that isotopic data is complex and should not be interpreted in isolation. Through the application of novel, high-resolution sampling methods, in combination with osteological techniques, it has been possible to establish a more nuanced understanding of the complex life history of an infant buried in the Early Iron Age cemetery at Zagorje ob Sazi, Slovenia.

Chapter 8 Results of oxygen Isotope analysis

8.1 Regional results of Oxygen Isotope Analysis

To explore themes of residential mobility and water sourcing in Late Bronze/ Early Iron Age Slovenia and north-eastern Croatia, oxygen isotope analysis was carried out on tooth enamel samples taken from non-adults and individuals that survived into adulthood. As previously explained in Section 3.2.3, this method of analysis has allowed for the investigation of $\delta^{18}O_{carb}$ values, calculated from carbonate fraction of human tooth enamel, which reflect the $\delta^{18}O$ values from local drinking water ($\delta^{18}O_{dw}$) (Daux et al. 2008; Chenery et al. 2012). These isotope ratios are affected by air temperature, altitude and distance from the sea (Longinelli and Selmo 2003). The $\delta^{18}O_{carb}$ values from tooth enamel only represent the $\delta^{18}O_{dw}$ of water ingested while the tooth crown was forming (Prowse et al. 2007). Therefore, the $\delta^{18}O_{carb}$ values presented here broadly represent the averaged isotopic composition of water ingested during childhood.

Numerous tooth types were sampled based on availability, including deciduous and permanent first (n=13) and second molars (n=12), canines (n=4), first incisors (n=4) and premolars (n=21). These teeth are the same as those analysed for enamel carbonate carbon analysis, discussed in Section 6.4. Crown formation times can be found in Table 8.1. The original $\delta^{18}O_{carb}$ values can be found in Appendix F, Disk 1, and mean $\delta^{18}O_{carb}$ values in Table 8.2. All tooth crowns will have completed formation by 8.5 years (+/- 0.5 years, second molar), except the third molar crown, which is complete at 15.5 years (+/- 0.5 years) (AlQahtani et al. 2010)). First molars, canines and incisors begin formation prior to one year and so are the most likely to be influenced by phases of breastfeeding and weaning. This would increase $\delta^{18}O_{carb}$ values relative to tooth enamel formed post-weaning (AlQahtani et al. 2010; Wright and Schwarcz 1998; Wright and Schwarcz 1999; Britton et al. 2015). The different tooth types have been compared in Table 8.2 and Figure 8.1 to investigate isotopic variability caused by the different developmental periods which they reflect. Mean $\delta^{18}O_{carb}$ values of tooth enamel formed during early childhood (excluding M3) exhibit a tight range of 1.2‰. The ranges of $\delta^{18}O_{carb}$ values do not reflect any trends in oxygen isotope ratios that would be indicative of breastfeeding, as M1, canine and incisor delta values plot in a similar way to tooth enamel developing in later childhood. If breastfeeding were significantly affecting the data, the ranges produced by the M1, canines and incisors would be expected to plot above that of premolars, and second and third molars (Wright and Schwarcz 1998; Wright and Schwarcz 1999; Britton et al. 2015). Following this test for variability, no difference has been identified between the $\delta^{18}O_{carb}$ values of different tooth types based on developmental period. Subsequently, $\delta^{18}O_{carb}$ values have been combined in this chapter to investigate themes of geographical origins and mobility.

Crown formation period	**CROWN INITIATION**	**CROWN COMPLETE**
First molar	4.5 Months +/- 1.5 Months	3.5 Years +/- 0.5 Years
Second molar	2.5 Years +/- 0.5 Years	8.5 Years +/- 0.5 Years
Third molar	8.5 Years +/- 0.5 Years	15.5 Years +/- 0.5 Years
Premolar	2.5 Years +/- 0.5 Years	6.5 Years +/- 0.5 Years
First Incisor	4.5 Months +/- 1.5 Months	2.5 Years +/- 0.5 Years
Canine	7.5 Months +/- 1.5 Months	5.5 Years +/- 0.5 Years
Deciduous first molar	30 Weeks in *Utero*	7.5 months +/- 1.5 months

Table 8.1. Crown formation times of teeth sampled for Oxygen Isotope Analysis (AlQahtani et al. 2010).

$\delta^{18}O_{carb}$‰	First molar (n=13)	Second molar (n=12)	Premolar (n=21)	Incisor (n=4)	Canine (n=4)	Third molar (n=1)
Mean	23.1	22.4	23.6	23.6	22.7	24.7
Standard deviation	0.6	0.8	1.4	0.9	2.4	0.0
IQR	1.1	0.9	2.3	1.1	0.8	0

Table 8.2. Mean, standard deviation and Interquartile ranges of $\delta^{18}O_{carb}$ values of different tooth types sampled

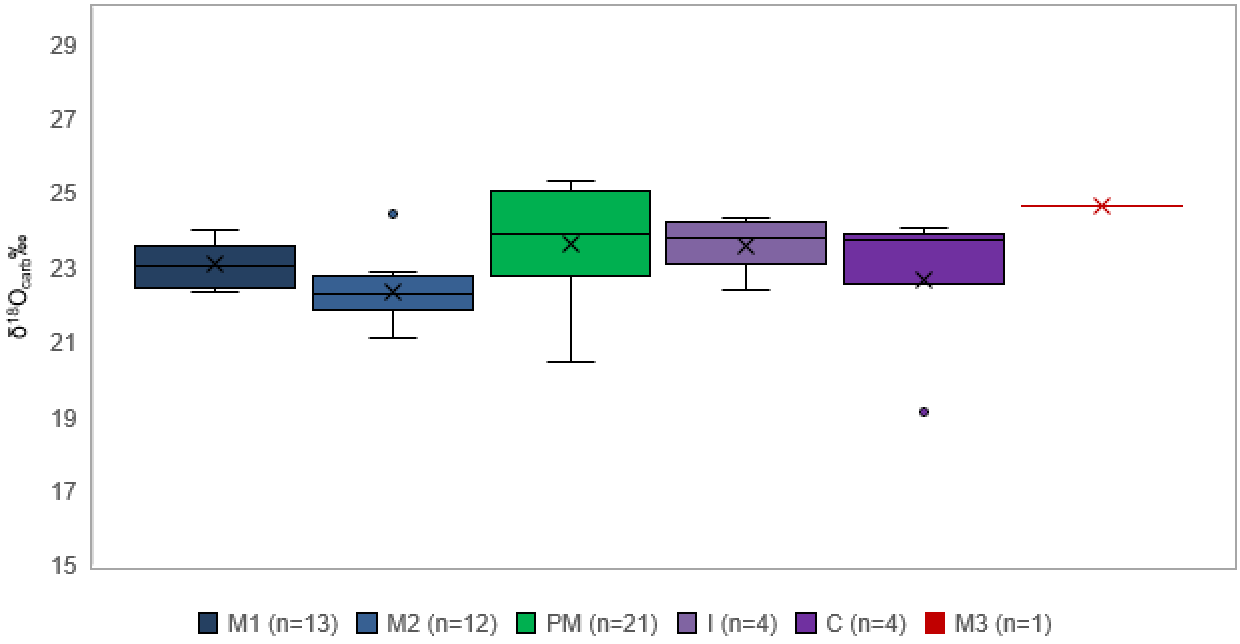

Figure 8.1 Box and whisker plot of $\delta^{18}O_{carb}$ values of different tooth types sampled. M1 = first molar; M2 = second molar; PM = premolar; I = incisor; C = canine; M3 = third molar. Little isotopic variation is exhibited between tooth types.

Following the application of conversion equations by Chenery (2012), which are presented in Section 3.2.3, the results of oxygen isotope analysis for all cemetery sites included as part of ENTRANS are given in Tables 8.3 and 8.4 and Figure 8.4. As in previous chapters, because the other strands of evidence available, Križna gora, Dolge njive and Obrežje are addressed in more detail in this chapter.

As has been demonstrated throughout the following chapter, this method of analysis has revealed a very complex situation when attempting to interpret $\delta^{18}O_{carb}$ and $\delta^{18}O_{dw}$ values from this study area. This is likely due to the intricate landscapes and climatic systems that characterise this area of central Europe. It is also likely that human activity, such as boiling or stewing, as well as breastfeeding and developmental stages, had an influence on $\delta^{18}O_{carb}$ values, as these activities have been shown to increase $\delta^{18}O_{carb}$ values (Brettell et al. 2012; Britton et al. 2015). The effects of these influences on $\delta^{18}O_{carb}$ values are addressed in more detail throughout this chapter. To reduce the potential biases caused by breastfeeding, deciduous teeth have not been included in interpretations of mobility and origins.

Ranges	Lowest $\delta^{18}O_{carb}$ ‰	Highest $\delta^{18}O_{carb}$ ‰	Range ‰	Lowest $\delta^{18}O_{dw}$‰	Highest $\delta^{18}O_{dw}$‰	Range ‰	Lowest $\delta^{18}O_p$‰	Highest $\delta^{18}O_p$‰	Range ‰
Dolge njive (n=9)	21.1	24.4	**3.3**	-15	-9.9	**5.1**	12.1	15.5	**3.3**
Križna gora (n=25)	19.1	25.3	**6.2**	-18.2	-8.3	**9.9**	10.1	16.5	**6.4**
Ljubljana Congress Square (n=5)	22.9	23.9	**1**	-12.9	-10.7	**2.2**	13.5	15	**1.5**
Obrežje (n=6)	21.9	24.5	**2.6**	-13.8	-9.7	**4.1**	12.9	15.6	**2.7**
Zagorje on Zavi (n=2)	22.2	23.5	**1.3**	-13.3	-11.2	**2.1**	13.3	14.6	**1.3**
Grofove njive (n=4)	21.5	23.6	**2.1**	-14.5	-11.2	**3.3**	12.5	14.6	**2.1**
Metlike/Hrib (n=2)	22.7	23.1	**0.4**	-12.5	-12	**0.5**	13.8	14.1	**0.3**
Sv Križ (n=4)	22.3	24.7	**2.4**	-13.2	-9.4	**3.8**	13.3	15.8	**2.5**
Sv Petar (=1)	24.9	24.9	**0**	-9	-9	**0**	16	16	**0**

Table 8.3. Ranges, Lowest and highest $\delta^{18}O_{carb}$ values $\delta^{18}O_{dw}$ values of each cemetery sampled for oxygen isotope analysis

MEAN	$\delta^{18}O_{carb}$ ‰	$\delta^{18}O_{dw}$ ‰	$\delta^{18}O_p$ ‰
Dolge njive (n=9)	22.6	-12.6	13.7
Križna gora (n=25)	23.6	-11.0	14.7
Ljubljana Congress Square (n=5)	23.0	-12.0	14.1
Obrežje (n=6)	23.4	-11.4	14.5
Zagorje ob Savi (n=2)	22.9	-12.2	13.9
Grofove njive (n=4)	22.5	-12.8	13.6
Metlika/hrib (n=2)	22.9	-12.2	14.0
Sv Križ (n=4)	23.3	-11.6	14.4
Sv Petar (n=1)	24.9	-9.0	16.0

Table 8.4. Mean $\delta^{18}O_{carb}$, $\delta^{18}O_{dw}$ and $\delta^{18}O_p$ values for each cemetery sampled for oxygen isotope analysis. $\delta^{18}O_{dw}$ and $\delta^{18}O_p$ values calculated from $\delta^{18}O_{carb}$ following equations by Chenery (2012)

8.2 Oxygen isotope studies of modern precipitation in Slovenia

Investigations into the isotopic composition of local precipitation collected at stations from across Slovenia have indicated that $\delta^{18}O$ values are strongly correlated to air temperature, and subsequently, $\delta^{18}O$ values were observed to vary significantly throughout the year (Vreča et al. 2005; Vreča et al. 2006; Vreča et al. 2007; Vreca et al. 2010). Some $\delta^{18}O$ values were recorded as low as -22.8‰ and as high as -3‰ from the station in Ljubljana (Vreca et al. 2010).

Station	Weighted mean	sampling ranges (monthly and daily, 2000-2003)
Ljubljana (1981-2006)	-8.6	-22.8 to -3.0
Portorož Airport (2001-2003)	-6.3	-14.9 to -0.8
Kozina (2001-2003)	-7.8	-17.5 to -1.1

Table 8.5. Ranges and weighted mean values of modern precipitation collected from three locations in Slovenia. Values are taken from Vreča et al. (2010)

For comparison with $\delta^{18}O_{dw}$ values estimated from human dental enamel, $\delta^{18}O$ values obtained from modern precipitation samples from three locations have been presented in Figure 8.2 and Table 8.5. In addition to air temperature, there are a couple of key factors that need to be considered when approaching $\delta^{18}O_{dw}$ values calculated from human tooth enamel. Slovenia consists of numerous distinctive landscapes including coastal and mountainous regions, valleys, and plains, within a relatively confined space.

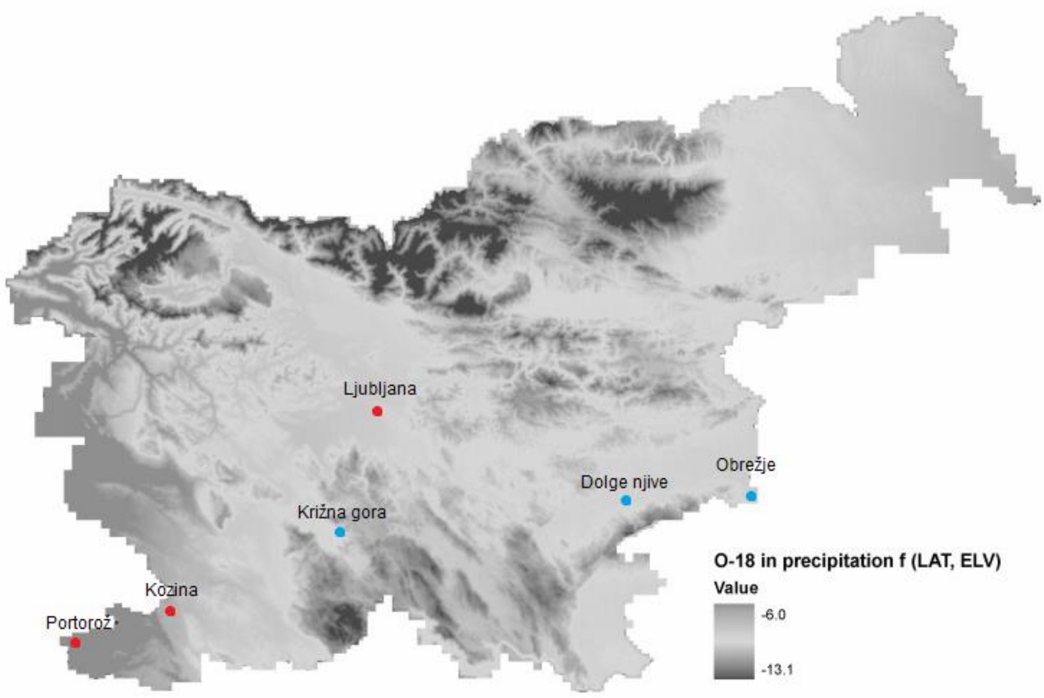

Figure 8.2. $\delta^{18}O$ map of Slovenia adapted from Vreča (2010: 320). The locations of the modern precipitation stations, as well as the cemeteries of Križna gora, Obrežje and Dolge njive have been added for reference

Vreča and colleagues (2010) have identified an altitude effect, where $\delta^{18}O$ values become more negative by between -0.27‰ and -0.33‰ per 100m. Furthermore, it has been observed that $\delta^{18}O$ values are influenced by the convergence of different major air masses sourced from the North Atlantic and the North Sea, maritime tropical air masses from the North Azores, and continental air masses from Scandinavia, Finland, Russia and the Pannonian plain (Vreča et al. 2005). These air masses carry with them precipitation from several sources, which are therefore composed of varying isotopic ratios (Vreča et al. 2005). Measuring precipitation samples taken monthly and daily from three stations, Vreča and colleagues could identify a range of $\delta^{18}O$ values across Slovenia of between -0.8‰ and -22‰ across a time span of three years from 2000 to 2003 (Vreča et al. 2005; Vreča et al. 2006; Vreča et al. 2007; Vreca et al. 2010).

This environment has subsequently created a complex situation when attempting to interpret human $\delta^{18}O_{dw}$ values from Slovenia. Before the whole data set is explored, individuals recovered from the Iron Age cemetery at Ljubljana Congress Square are presented as a case study, to examine how $\delta^{18}O$ values from modern precipitation might relate to $\delta^{18}O_{carb}$ and $\delta^{18}O_{dw}$ values measured in and estimated from prehistoric tooth enamel.

8.3 Ljubljana Congress Square

Very few samples could be recovered from this site because of poor bone preservation. The samples that have been included most likely only represent three separate individuals, with deciduous and permanent teeth sampled from the double, non-adult grave: 1029. The $\delta^{18}O_{carb}$ values measured from the tooth enamel of these three individuals are presented in Table 8.6, and the $\delta^{18}O_{dw}$ values calculated from these in Figure 8.3.

Figure 8.3 presents the weighted mean $\delta^{18}O$ value of modern precipitation collected at Ljubljana between 2000 and 2003 as a red line (-8.6‰). The black line represents the mean $\delta^{18}O_{dw}$ value calculated from the enamel carbonate results from Ljubljana Congress Square (-12.0‰).

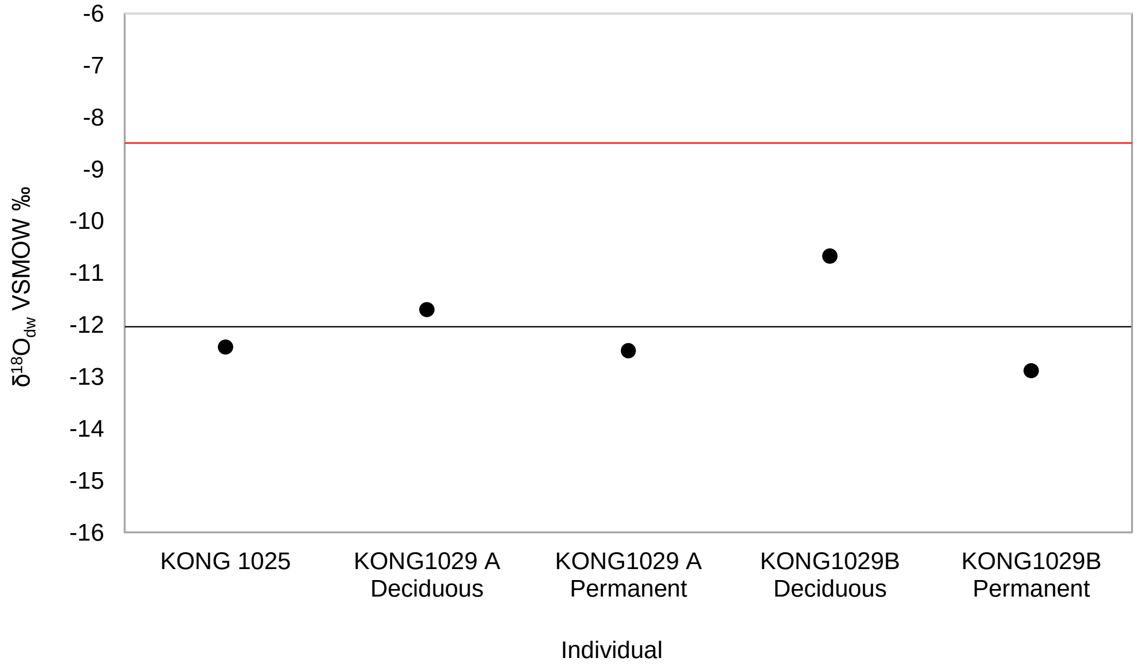

Figure 8.3. A plot of $\delta^{18}O_{dw}$ values from Ljubljana Congress Square. The mean value of -12‰ has been indicated as a black line, while the weighted mean value of modern precipitation from Ljubljana Congress Square is plotted as a red line.

The $\delta^{18}O_{dw}$ values from these Iron Age Individuals do not reflect the same mean value as that of modern precipitation, which is ~3.4‰ more positive. This suggests that $\delta^{18}O_{dw}$ values obtained from prehistoric tooth enamel will not necessarily relate to that of local, modern $\delta^{18}O$ values calculated by other laboratories. Moreover, if $\delta^{18}O_{dw}$ values from enamel carbonate vary from modern $\delta^{18}O$ values, this may not be linked to mobility. This corroborates with recent investigations, which argue that the errors generated during the conversion of $\delta^{18}O_{carb}$ values to $\delta^{18}O_{dw}$ estimates are creating difficulties when attempting to contribute $\delta^{18}O_{dw}$ values to particular geographical locations (Pollard et al. 2011). Furthermore, investigations into inter-laboratory variation have also raised serious concerns regarding the direct comparison of $\delta^{18}O_{carb}$ values measured at different laboratories (Pestle et al. 2014). This has been attributed to the variable preparation and analytical methodologies (Pestle et al. 2014). The difference observed between the modern precipitation isotope ratios and that of $\delta^{18}O_{carb}$ values are probably revealing a systematic shift in isotope data because of inter-laboratory variability, rather than climatic or environmental change (Pestle et al. 2014). For this reason, the direct comparison of $\delta^{18}O_{carb}$ values obtained from archaeological samples and modern precipitation data is not recommended.

Congress Square			
Identifier	*$\delta^{18}O_{dw}$‰*	*$\delta^{18}O_{carb}$ VSMOW ‰*	*$\delta^{18}O_{p}$‰*
KONG 1025	-12.4	22.8	13.8
KONG1029 A Deciduous	-11.7	23.2	14.3
KONG1029 A Permanent	-12.5	22.7	13.8
KONG1029B Deciduous	-10.7	23.9	15.0
KONG1029B Permanent	-12.9	22.5	13.5
MEAN	**-12.0**	**23.0**	**14.1**
Standard deviation	**0.8**	**0.5**	**0.6**

Table 8.6. $\delta^{18}O_{carb}$ values, and $\delta^{18}O_{dw}$ and $\delta^{18}O_{p}$ estimates from Ljubljana Congress Square. $\delta^{18}O_{dw}$ and $\delta^{18}O_{p}$ calculated using equations in Chenery et al. (2012)

Furthermore, as shown in Table 8.1, there appears to be much more variability within $\delta^{18}O_{dw}$ values than either $\delta^{18}O_{carb}$ values or $\delta^{18}O_{p}$ estimates. This probably because of the increased error created when applying conversion equations (Pollard et al. 2011; Chenery et al. 2012; Britton et al. 2015)

As the purpose of this investigation was to explore the potential for inter and intra-population isotopic variation, rather than ascribing specific geographical locations to individuals, isotope ratios that have not undergone a conversion ($\delta^{18}O_{carb}$) have also been presented, rather than converted ratios, throughout this chapter. These values will only be associated with a relatively minimal measurement error (Pollard et al. 2011; Britton et al. 2015). This will ensure that interpretations made using converted ratios are not biased because of errors associated with conversion equations. The comparison of unconverted delta values has previously been done in other investigations into oxygen isotope ratios (Müldner et al. 2011; Britton et al. 2015).

8.4 Regional overview

As shown in Tables 8.3 and 8.4, and Figure 8.4, $\delta^{18}O_{carb}$ values are largely consistent within and between cemetery sites, with mean values falling between 22.5 and 24.9‰. This overall consistency in most $\delta^{18}O_{carb}$ values suggests there is little apparent evidence of residential migration. Furthermore, most $\delta^{18}O_{carb}$ values overlap between sites, and subsequently, there is little evidence for cemetery specific ranges of $\delta^{18}O_{carb}$ values.

Although there appears to be a relatively broad scatter of data points around the ENTRANS mean (23.3‰) for $\delta^{18}O_{carb}$ values, most individuals fall within one standard deviation, or comfortably within two standard deviations. The most scatter around the mean $\delta^{18}O_{carb}$ value was identified in the data set from Križna gora (diamonds). Here there are two individuals that are potential outliers (Graves 22 and 32), which have been indicated in Figures 8.3 and 8.4, and further explained in Section 8.5.1.

To assess the results of oxygen isotope analysis for potential outliers or homogeneity, unconverted $\delta^{18}O_{carb}$ values shall be investigated through the use of standard deviations, interquartile ranges and other descriptive measures, such as mean and median values.

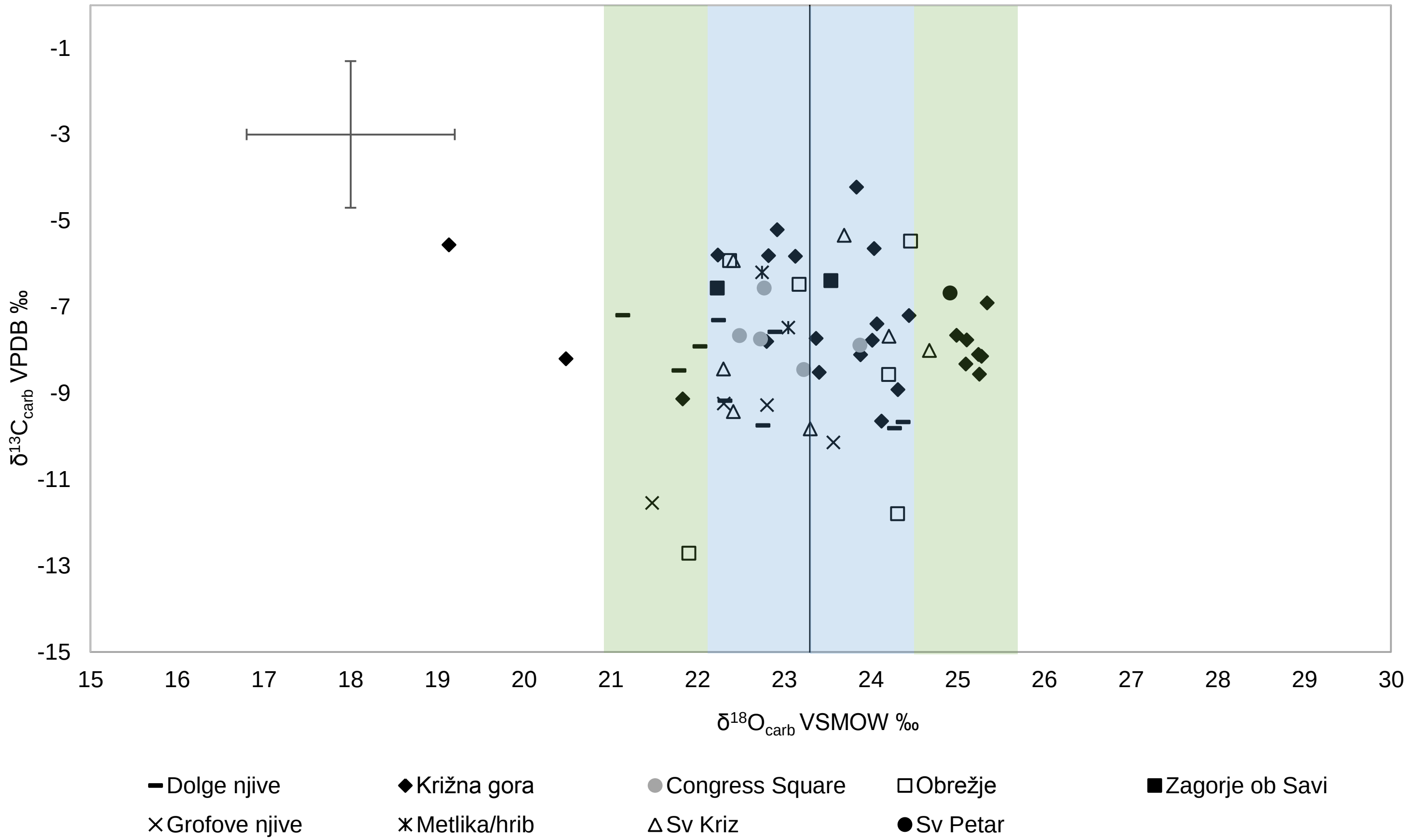

Figure 8.4. A plot of $\delta^{13}C_{carb}$ and $\delta^{18}O_{carb}$ values from the whole oxygen isotope data set. The error bars represent 1 standard deviation. The black line represents the mean $\delta^{18}O_{carb}$ value of 23.3‰ for the whole data set. The blue area represents up to 1 standard deviation around the mean value, while the green shaded area represents between 1 and 2 standard deviations. Two data points plot outside of 2 standard deviations. These are Križna gora graves 22 and 32.

8.5 Site level overview

In this section of the chapter, the cemetery sites of Križna gora, Dolge njive and Obrežje will be examined in more detail, as has been done in previous chapters.

8.5.1 Križna gora

As with the carbon and nitrogen isotope data set explored in Chapter 6, the results of oxygen isotope analysis on the cemetery site at Križna gora makes up the largest site-based oxygen isotopic data set available to this project. 25 samples from 24 individuals were taken.

The results of oxygen isotope analysis on enamel carbonate from remains recovered at Križna gora can be found in Figure 8.6 and in Table 8.7. As has been done in Figure 8.4 at the regional scale, Figure 8.5 displays a site-specific mean as a black line, with one standard deviation shaded in blue and two standard deviations in green.

$\delta^{18}O_{carb}$ values of individuals from Križna gora cluster mainly between ~ 22 and ~ 25‰, with an overall range of 6.2‰. There are two potential outliers with $\delta^{18}O_{carb}$ values of 19.1‰ (KG 22) and 20.5‰ (KG 32). As has been demonstrated in Figure 8.5, these two values are higher than two standard deviations (+/- 3‰) from the site mean of 23.6‰. These two individuals are also outliers of the whole data set, both falling outside 2 standard deviations (+/- 2.6‰) from the data set mean of 23.3‰. This could indicate non-local individuals, but the use of oxygen isotope ratios alone is probably not enough to confirm this. As has already been explained, the ranges of modern precipitation $\delta^{18}O$ values have been identified in excess 19‰ (Vreca et al. 2010). However, the positioning on the plot above two standard deviations does mark these two individuals as being unusual. As they have been highlighted as outliers, they shall be revisited in later investigations into, for example, grave type and grave goods, to investigate whether there are any other indications that these two individuals were anomalous. It has already been established in prior chapters that these two individuals shared a similar diet to that of the rest of the cemetery group, with $\delta^{13}C$ values from multiple elements (including dentine) of between ~-15‰ to -16‰, and $\delta^{15}N$ values of between 8.5‰ to 10‰. This gives no supporting evidence that these persons were non-locals.

Križna gora (n=25)			
Identifier	*$\delta^{18}O_{dw}$‰*	*$\delta^{18}O_{carb}$ VSMOW ‰*	*$\delta^{18}O_{p}$‰*
KG 2	-12.4	22.8	13.8
KG 7	-10.7	23.8	14.9
KG 22	-18.2	19.1	10.1
KG 30	-10.4	24.1	15.2
KG 32	-16.1	20.5	11.5
KG 57	-12.3	22.8	13.9
KG 59	-10	24.3	15.4
KG 62	-11.5	23.4	14.4
KG 63	-11.9	23.1	14.2
KG 65	-13.3	22.2	13.3
KG 67	-10.3	24.1	15.2
KG 70	-8.7	25.1	16.2
KG 72	-8.7	25.1	16.2
KG 75A	-8.9	25	16.1
KG 75B	-10.4	24	15.1
KG 76	-9.8	24.4	15.5
KG 77	-8.3	25.3	16.5
KG 79	-12.2	22.9	14.0
KG 81	-13.9	21.8	12.8
KG 83	-8.5	25.3	16.4
KG 84	-10.4	24	15.1
KG 85	-10.7	23.9	15.0
KG 103	-11.4	23.4	14.5
KG 124	-8.5	25.2	16.4
KG 129	-8.4	25.3	16.4
MEAN	**-11**	**23.6**	**14.7**
Standard deviation	**2.4**	**1.5**	**1.6**

Table 8.7. $\delta^{18}O_{carb}$ values, and $\delta^{18}O_{dw}$ and $\delta^{18}O_{p}$ estimates from Križna gora. $\delta^{18}O_{dw}$ and $\delta^{18}O_{p}$ calculated using equations in Chenery et al. (2012)

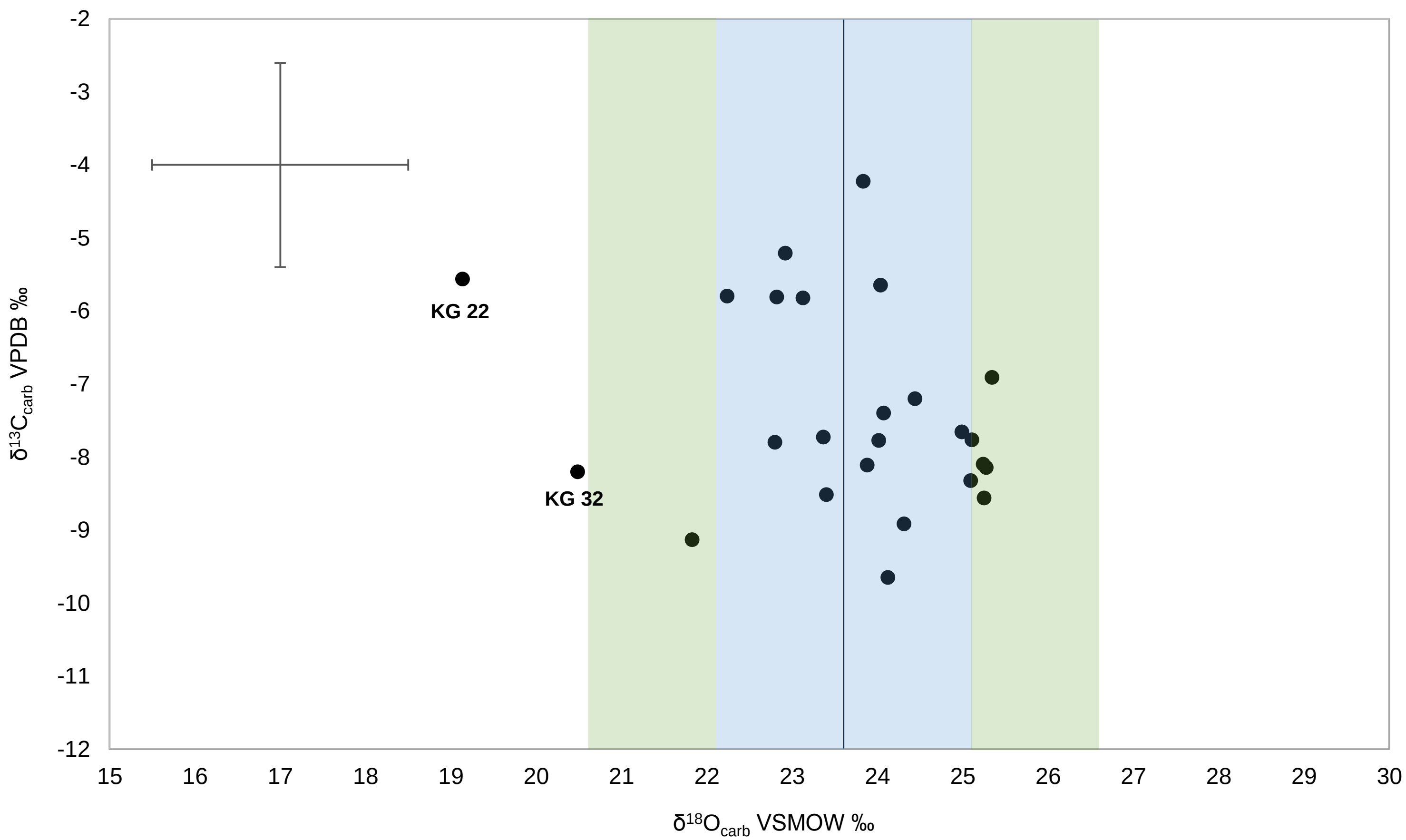

Figure 8.5.A plot of $\delta^{13}C_{carb}$ and $\delta^{18}O_{carb}$ values from Križna gora. The error bars represent 1 standard deviation. The black line represents the mean $\delta^{18}O_{carb}$ value of 23.6‰. The blue area represents up to 1 standard deviation around the mean value, while the green shaded area represents between 1 and 2 standard deviations. Two data points plot outside of 2 standard deviations. These are Križna gora Graves 22 and 32.

If the two outliers are removed from the Križna gora data set, the spread of $\delta^{18}O_{carb}$ values is between 21.8‰ and 25.3‰, with a range of 3.5‰. Most $\delta^{18}O_{carb}$ values fall within one standard deviation (+/- 1.5‰), with five $\delta^{18}O_{carb}$ values falling within two standard deviations.

As can be observed in Figure 8.6, the immediate area around Križna gora is a diverse environment of uplands and lowlands, with the cemetery itself found at the top of a hill. The range of $\delta^{18}O_{carb}$ values from the individuals buried here could be reflecting $\delta^{18}O_{carb}$ values relative to their localised, assorted landscape and the climatic variability that is probably associated with it.

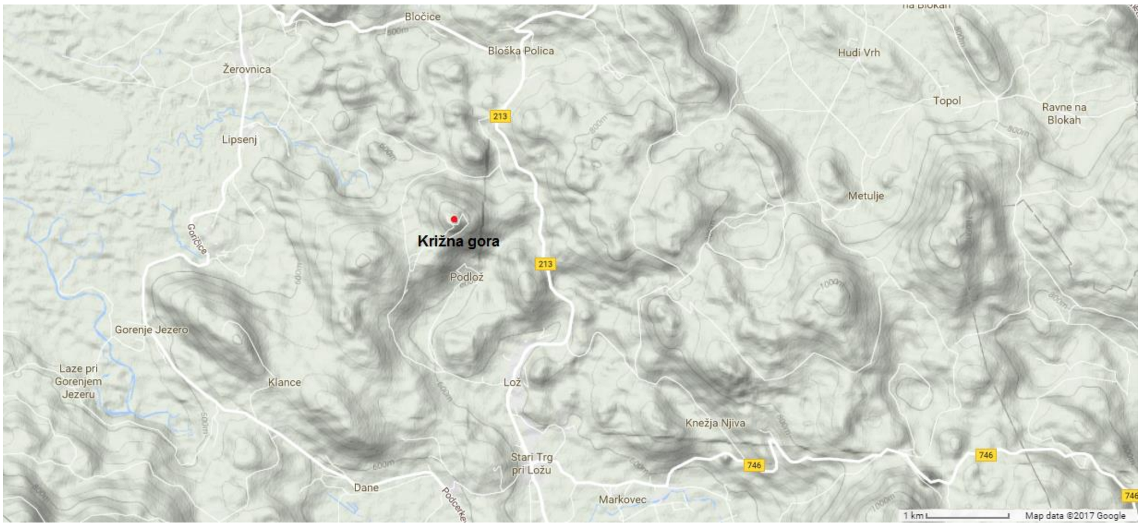

Figure 8.6. Topographical map of the landscape surrounding Križna gora. Adapted from google maps (June 2017)

The oxygen isotope ratios collected from the tooth enamel carbonate of people buried at Križna gora have indicated that there may be wide ranges of possible local $\delta^{18}O_{carb}$ values. Although a relatively wide scatter around the mean has been identified, there is little definitive evidence to suggest residential mobility, other than, perhaps, the two individuals buried in Graves 22 and 32.

A settlement site has been identified above that of the cemetery on the same hill (Urleb 1974; M. Črešnar pers comm). However, it is also important to consider that a cemetery may have served more than one settlement, and so people from this cemetery catchment could have inhabited slightly different environments. This may have contributed to the variability seen within this group.

8.5.2 Dolge njive

The nine $\delta^{18}O_{carb}$ values from Dolge njive fall between 21.1 and 24.4**‰,** with a range of 3.3‰. As shown in Table 8.8, and Figure 8.7, all the data points for the $\delta^{18}O_{carb}$ values plot within two standard deviations from the site mean ($\delta^{18}O_{carb}$ = 22.6 +/- 1‰), with most falling within one standard deviation. This is evidence to suggest that these individuals were consuming water with a similar isotopic composition.

The exact location of the settlements associated with this cemetery is uncertain. The settlement for Dolge njive could be the Vinji vrh hillfort, or just below, where the village of Bela Cerkev is now located, though only one structure and a river landing stage (cobbled surface) was uncovered (P. Mason pers comm. 2017).

To further investigate whether this cemetery included individuals from different geographical origins, they have been included in a pilot study using strontium isotope analysis. The results of this investigation, also including seven samples from Križna gora, can be found in Chapter 9.

Dolge njive (n=9)			
Identifier	$\delta^{18}O_{dw}$‰	$\delta^{18}O_{carb}$ *VSMOW ‰*	$\delta^{18}O_{p}$‰
DN1772	-13.1	22.3	13.4
DN1781	-13.6	22	13.1
DN2603	-12.5	22.8	13.8
DN2604	-14	21.8	12.8
DN2680	-13.3	22.2	13.3
DN2903	-12.2	22.9	13.9
DN2359	-10	24.3	15.4
DN3935	-9.9	24.4	15.5
DN2900	-15	21.1	12.1
MEAN	**-12.6**	**22.6**	**13.7**
Standard deviation	**1.6**	**1**	**1.1**

Table 8.8. $\delta^{18}O_{carb}$ values, and $\delta^{18}O_{dw}$ and $\delta^{18}O_{p}$ estimates from Dolge njive. $\delta^{18}O_{dw}$ and $\delta^{18}O_{p}$ calculated using equations in Chenery et al. (2012)

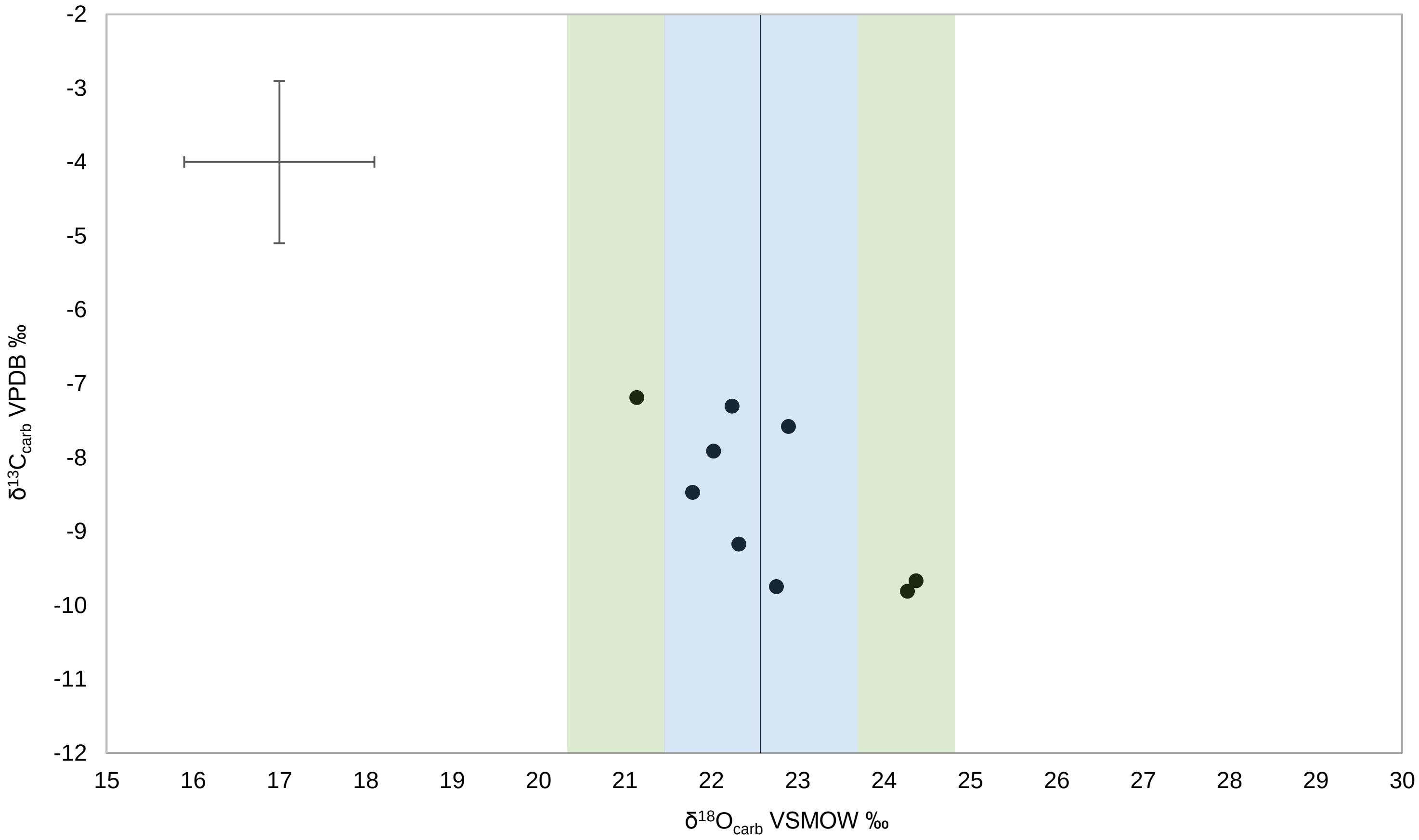

Figure 8.7. A plot of $\delta^{13}C_{carb}$ and $\delta^{18}O_{carb}$ values from Dolge njive. The error bars represent 1 standard deviation. The black line represents the mean $\delta^{18}O_{carb}$ value of 22.6‰. The blue area represents up to 1 standard deviation around the mean value, while the green shaded area represents between 1 and 2 standard deviations. All of the individuals from this site plot within two standard deviations from the mean

8.5.3 Obrežje

Throughout this thesis, the site of Obrežje has been examined because of its unusual context and deep chronology. Here, this cemetery group is again investigated, through the examination of oxygen isotope analysis, the results of which are presented in Table 8.9. The individuals plotted in Figure 8.8 are separated on the Y-axis due to a difference in the isotopic composition of diet. This observation was previously addressed in Sections 6.4.3 and 6.5.1.

During the interpretation of the $\delta^{13}C$ and $\delta^{15}N$ values of individuals dated to the Middle and Late Bronze Age, and the Iron Age, it was posited that variation across the whole diet of these individuals could be due to differences in geographical residency during the period of tooth formation, with the two individuals buried in grave 3043 being non-locals. The application of oxygen isotope analysis has shown that $\delta^{18}O_{carb}$ values from the individuals buried in this cemetery are similar, varying between 21.9‰ and 24.5‰, with a range of 2.6‰.

The two data points indicated by the arrow on Figure 8.8 represent a deciduous and permanent tooth from the same individual (Ob 12664). The intra-individual variation in $\delta^{18}O_{carb}$ values (2.1‰) between the deciduous and permanent teeth from Obrežje 12664, is comparable to the inter-individual variation from across the whole cemetery group (2.6‰). This variation in $\delta^{18}O_{carb}$ values is discussed further in Section 8.6, investigating shifts between deciduous and permanent teeth.

Obrežje (n=6)			
Identifier	*$\delta^{18}O_{dw}$‰*	*$\delta^{18}O_{carb}$ VSMOW ‰*	*$\delta^{18}O_{p}$‰*
OB 2544 (Iron Age)	-9.7	24.5	15.6
OB 2828 (Undated)	-11.8	23.2	14.2
OB 12664 Deciduous (Middle Bronze Age)	-10.1	24.2	15.3
OB 12664 Permanent (Middle Bronze Age)	-13.1	22.4	13.4
OB POT (Late Bronze Age)	-10	24.3	15.4
OB 3043 (Late Bronze Age)	-13.8	21.9	12.9
MEAN	**-11.4**	**23.4**	**14.5**
Standard deviation	**1.6**	**1**	**1.1**

Table 8.9. $\delta^{18}O_{carb}$ values, and $\delta^{18}O_{dw}$ and $\delta^{18}O_{p}$ estimates from Obrežje. $\delta^{18}O_{dw}$ and $\delta^{18}O_{p}$ calculated using equations in Chenery et al. (2012)

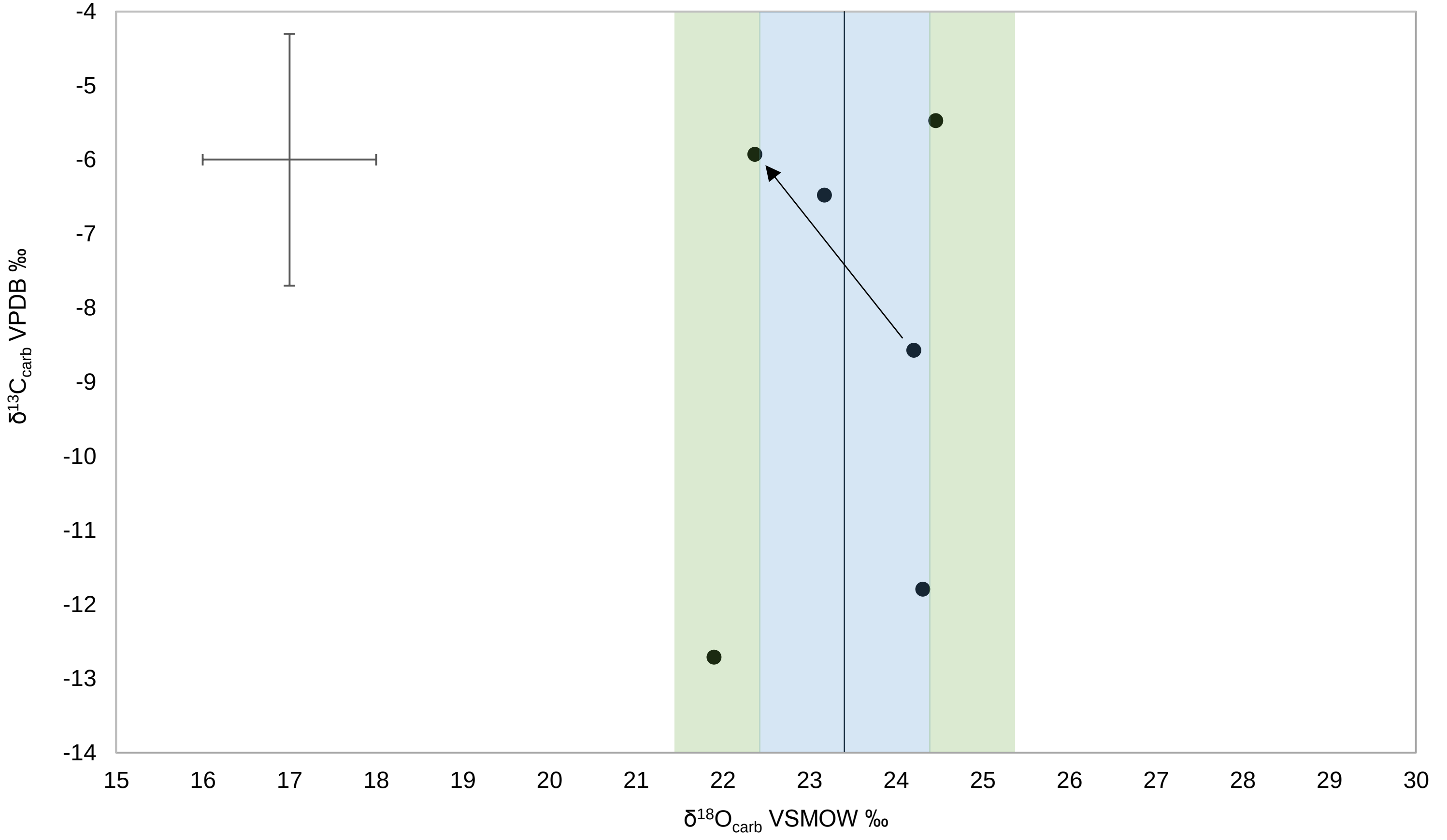

Figure 8.8. A plot of $\delta^{13}C_{carb}$ and $\delta^{18}O_{carb}$ values from Obrežje (n=6). The error bars represent 1 standard deviation. The black line represents the mean $\delta^{18}O_{carb}$ value of 23.4‰. The blue area represents up to 1 standard deviation around the mean value, while the green shaded area represents between 1 and 2 standard deviations. The black arrow indicates the paired deciduous and permanent tooth samples from the non-adult buried in grave 12664. All of the individuals from this site plot within two standard deviations from the mean.

This site was revisited over the centuries for funerary activity. This is a unique phenomenon within the ENTRANS dataset. The site of Kapiteljska njive, for example, was seen to be used continuously throughout the Urnfield period and into the Iron Age, but it does not appear to be the same situation at Obrežje. This site is, first and foremost, an urnfield cemetery focussing on the funerary rite of cremation. These few inhumations, with such an unexpected chronology, are therefore anomalous inclusions.

Some explanations for this exceptional burial treatment could be that this small group of inhumation burials represent individuals that followed different belief systems, that they were deviants, or that they were from outside of the local community. As already discussed in Section 2.2, except for two bronze dress pins (Graves 2544 and 2828) and a single cup (containing the very fragmented and incomplete remains of an adult and non-adult in Grave 3043), these individuals were not buried with grave goods to indicate any social standing or place of origin.

Unfortunately, as the other human remains from this cemetery were very well cremated and fragmentary, they were not included as part of this study. Therefore, it was not possible to obtain oxygen ratios for individuals making up the 'normal' urnfield cemetery group for isotopic comparison. Any large differences in the oxygen isotope ratios obtained from these inhumed individuals, or when compared to the rest of the ENTRANS dataset, could provide evidence for the hypothesis of immigration. If there is no significant difference, this would not necessarily provide evidence against this hypothesis. As this chapter has already illustrated, there are relatively wide ranges in oxygen isotope ratios available from across this study area. No difference in the oxygen isotope ratios would suggest that this form of analysis is not enough to answer this complex question and that other evidence is required.

Overall, there is little evidence to suggest that the individuals buried at this cemetery were non-locals. As has already been discussed, individuals sampled from across Slovenia have provided diverse ranges of $\delta^{18}O_{carb}$ ranges, which are observed to overlap among different sites. All the isotope ratios obtained from Obrežje fall comfortably within these ranges and do not differ significantly between one another. The variability seen within this small data set could have been the result of numerous scenarios, apart from that of immigration. These are explored in more detail below.

8.6 Inter-tooth oxygen isotope variation between deciduous and permanent teeth

Figures 8.9 and 8.10, and Tables 8.10, 8.11 and 8.12 have been used to display a disparity in $\delta^{18}O_{carb}$ values observed between deciduous and permanent teeth from the same individual. $\delta^{18}O_{carb}$ values of deciduous tooth enamel are on average 1.2‰ higher than that of permanent tooth enamel. The difference in $\delta^{18}O_{carb}$ values between paired deciduous and permanent teeth ranges between 0.5 and 1.8‰. This range in values is further illustrated as a box and whisker plot in Figure 8.10, where three-quarters of the deciduous tooth data plots above the interquartile range of the permanent tooth data. The largest difference is observed between paired tooth enamel samples of Obrežje 12664.

Non-adult individual	$\delta^{18}O_{dw}$‰	Inter-tooth difference ($\delta^{18}O_{dw}$‰)	$\delta^{18}O_{carb}$‰	Inter-tooth difference ($\delta^{18}O_{carb}$‰)	$\delta^{18}O_{p}$‰	Inter-tooth difference ($\delta^{18}O_{p}$‰)
KG 75 deciduous	-8.9	**1.5**	25.0	**1.0**	16.1	**1.0**
KG 75 permanent	-10.4		24.0		15.1	
KONG 1029A deciduous	-11.7	**0.8**	23.2	**0.5**	14.3	**0.5**
KONG 1029A permanent	-12.5		22.7		13.8	
KONG 1029B deciduous	-10.7	**2.2**	23.9	**1.4**	15.0	**1.4**
KONG 1029B Permanent	-12.9		22.5		13.5	
OB 12664 deciduous	-10.1	**2.9**	24.2	**1.8**	15.3	**1.9**
OB 12664 permanent	-13.1		22.4		13.4	
Križ 4 deciduous	-11.6	**1.4**	23.3	**0.9**	14.4	**0.9**
Križ 4 permanent	-13.0		22.4		13.5	

Table 8.10. $\delta^{18}O_{carb}$ values, and $\delta^{18}O_{dw}$ and $\delta^{18}O_{p}$ estimates from paired deciduous and permanent tooth enamel samples. $\delta^{18}O_{dw}$ and $\delta^{18}O_{p}$ calculated using equations in Chenery et al. (2012)

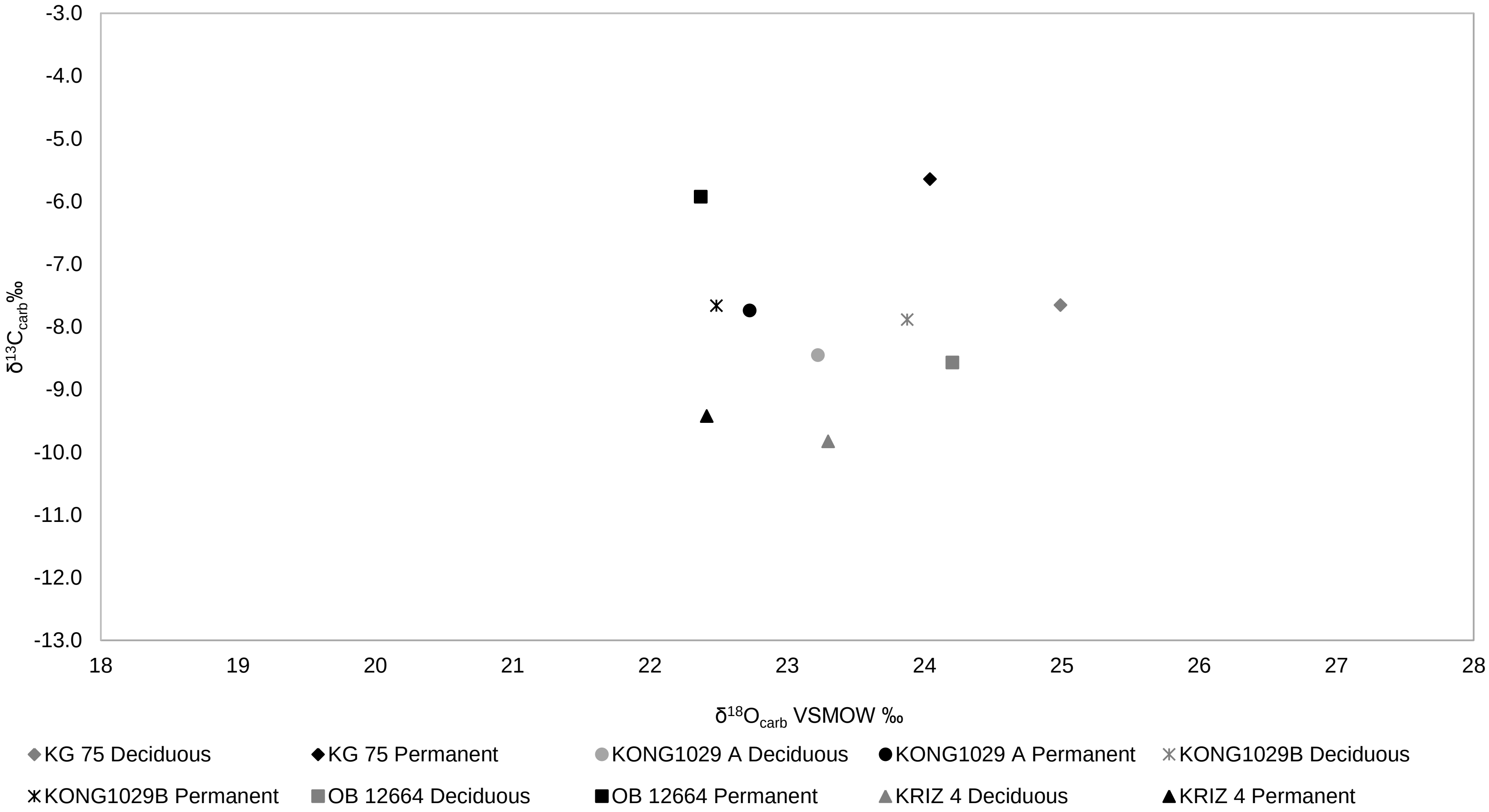

Figure 8.9. The plot of $\delta^{18}O_{carb}$ values from paired deciduous and permanent tooth samples from different cemeteries. Deciduous tooth samples are coloured grey and permanent samples in black. $\delta^{18}O_{carb}$ values from deciduous teeth are consistently higher than paired permanent teeth, indicating an enrichment in ^{18}O in deciduous tooth enamel compared with permanent tooth enamel.

Figure 8.10. Box and whisker plot comparing $\delta^{18}O_{carb}$ values of deciduous (n=5) and permanent (n=5) tooth enamel. Samples from different sites have been combined. Roughly half of the data from the deciduous teeth category plots above three-quarters of the data from the permanent teeth category. This indicates a common enrichment in ^{18}O in deciduous tooth enamel, relative to permanent tooth enamel

Category	$\delta^{18}O_{carb}$ VSMOW ‰
Deciduous teeth (n=5)	
Median	24.0
Mean	24.1
Permanent teeth (n=5)	
Median	22.6
Mean	22.9

Table 8.11. Mean and Median $\delta^{18}O_{carb}$ values of deciduous and permanent tooth enamel

Interquartile range	Q1 ($\delta^{18}O_{carb}$‰)	Q3 ($\delta^{18}O_{carb}$‰)
Deciduous teeth (n=5)	24.4	23.7
IQR	0.7	
Permanent teeth (n=5)	23.2	22.4
IQR	0.8	

Table 8.12. First quartile values, third quartile values, and Interquartile range of $\delta^{18}O_{carb}$ values of deciduous and permanent tooth enamel

This variability between the permanent and deciduous teeth could be reflecting a couple of different scenarios. This may include breastfeeding and weaning, as the isotopic composition of breast milk and drinking water is different (Wright and Schwarcz 1998; Wright and Schwarcz 1999; Britton et al. 2015). Another possible cause could be residential mobility during the period of dental development (Prowse et al. 2007). Alternatively, variable $\delta^{18}O_{carb}$ values between the teeth may be reflecting inconsistent climatic conditions during the period of enamel mineralisation (Prowse et al. 2007). These potential interpretations are addressed below.

8.7 Thematic interpretations of oxygen isotope ratios

8.7.1 Potential causes of oxygen isotope variability

Breastfeeding and weaning

In Section 8.6 of this chapter, a shift in the oxygen isotope ratios was identified between the deciduous and permanent teeth belonging to the same individual. In previous studies, it has been argued that this movement from more to less negative $\delta^{18}O_{dw}$ values (or from higher to lower $\delta^{18}O_{p}$ and $\delta^{18}O_{carb}$ values) is the result of the transition from the ingestion of breast milk as the main source of water, to the consumption of local drinking water (Wright and Schwarcz 1998; Wright and Schwarcz 1999; Britton et al. 2015). This is based on the premise that breast milk is more enriched in ^{18}O relative to the drinking water of the lactating mother. This is because of the isotopic fractionation that occurs in the body, whereby ^{16}O is preferentially lost during expiration as $H_2{}^{16}O$, leaving the body water relatively enriched in ^{18}O (Wright and Schwarcz 1998; Wright and Schwarcz 1999; Britton et al. 2015). Breast milk is subsequently synthesised from this pool of isotopically enriched body water, causing the breast milk to likewise become enriched in ^{18}O relative to the local drinking water (Wright and Schwarcz 1998; Wright and Schwarcz 1999; Britton et al. 2015). Therefore, an infant ingesting a high quantity of breast milk will form tissues reflecting this isotopic enrichment and, furthermore, that these tissues will produce higher $\delta^{18}O$ values than those of an individual that is not breastfeeding (Wright and Schwarcz 1998; Wright and Schwarcz 1999; Britton et al. 2015). When the quantity of breast milk is reduced as the infant is weaned, the forming tissues will reflect less and less of this ^{18}O enrichment. The shift from higher to lower $\delta^{18}O_{carb}$ values, therefore, is a method of tracking the relative importance of breast milk versus other liquids (Wright and Schwarcz 1998; Wright and Schwarcz 1999; Britton et al. 2015).

Distinctions in the carbon isotope ratios from tooth enamel of paired deciduous and permanent teeth (from the same teeth as those discussed here), have already suggested that shifts in $\delta^{13}C_{carb}$ values are likely related to the onset of weaning, the movement away from a high lipid diet (breast milk), and the introduction of carbohydrates (Wright and Schwarcz 1998). The shift in the oxygen isotope ratios from higher to lower $\delta^{18}O_{carb}$ values between paired deciduous and permanent teeth also supports this hypothesis, suggesting that the onset of weaning occurred during the mineralisation of the permanent tooth crowns, i.e. prior to 3.5 years of age (for permanent first molars) (AlQahtani et al. 2010).

Changes in elevation and residential mobility

Figure 8.11 is a box and whisker plot comparing the $\delta^{18}O_{carb}$ values produced by individuals buried at each cemetery. This Figure illustrates the similarities in $\delta^{18}O_{carb}$ values among these groups, with small isotopic variations. Larger spreads of data from, for example, Križna gora, have probably been influenced by variable sample sizes, rather than notable differences between cemeteries.

With the similarities between $\delta^{18}O_{carb}$ values from individuals buried the same site (within one or two standard deviations from the mean), there is little evidence to support an argument for long distance residential mobility. However, as has also been observed, ranges in apparently local $\delta^{18}O_{carb}$ values from several different cemetery sites across central and eastern Slovenia have also been shown to overlap. With such a broad variability seen in the modern $\delta^{18}O$ values and in the $\delta^{18}O_{carb}$ values from dental enamel, it could be the case that mobility was occurring between these communities, but that it is not detectable using this method. Therefore, the potential for movement around prehistoric Slovenia and the surrounding landscape cannot be ruled out based on these results.

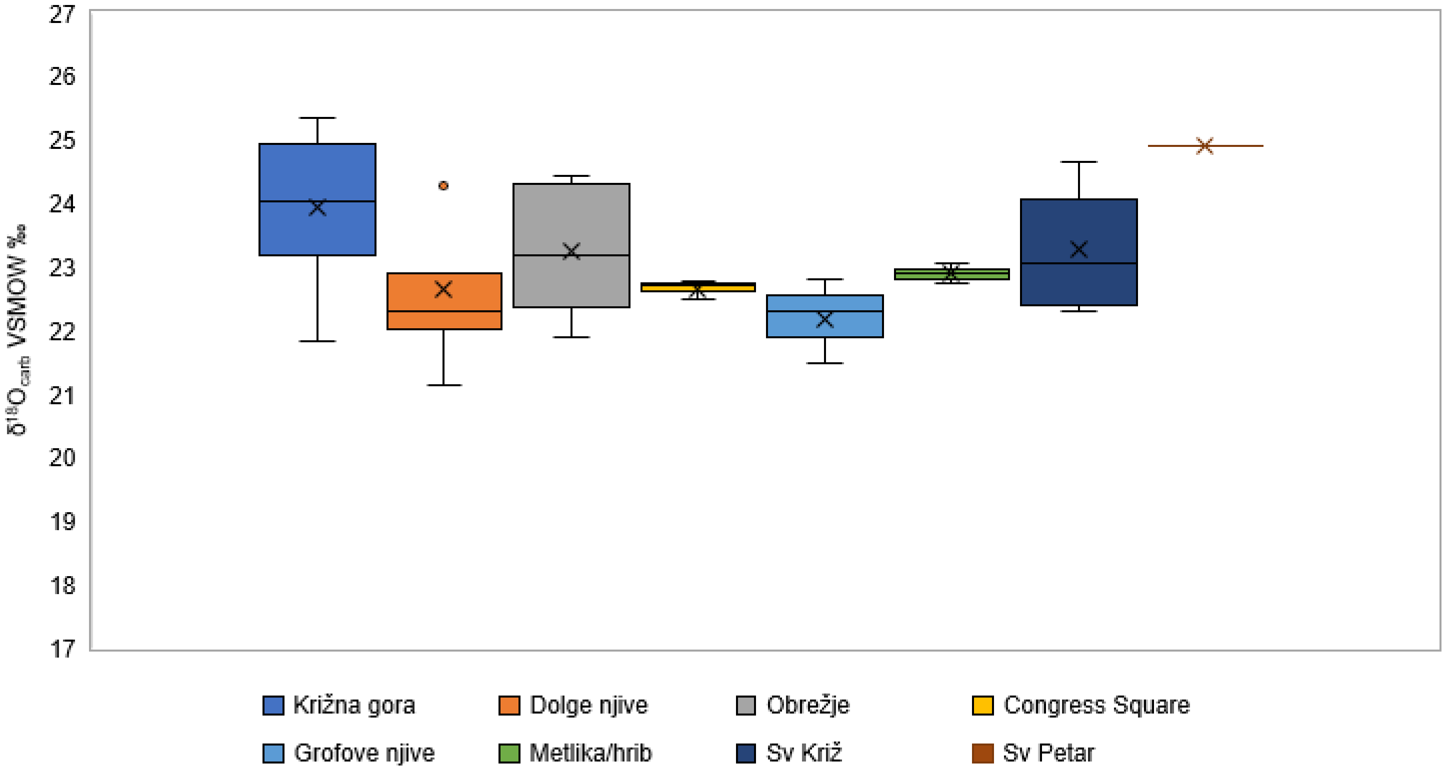

Figure 8.11. Box and whisker plot comparing $\delta^{18}O_{carb}$ values from different cemeteries

Another potential cause of oxygen isotope variation would be where individuals were sourcing their drinking water from. If individuals were consuming standing or stored water, that had undergone evaporation or water from rivers fed by different tributaries, this would have increased the $\delta^{18}O$ of drinking water (Brettell et al. 2012; Lightfoot et al. 2014a; Britton et al. 2015). This could have been influenced further still during stewing, brewing, vinification (during grape cultivation, rather than the process itself) and boiling, which can result in higher $\delta^{18}O_{carb}$ values due to isotopic fractionation during evaporation (Brettell et al. 2012; Lightfoot et al. 2014a). These are also arguably activities that are related to social and cultural practices, perhaps with social restrictions placed on water sources or liquid types (Brettell et al. 2012; Lightfoot et al. 2014a; Britton et al. 2015). For these factors to affect the $\delta^{18}O_{carb}$ values during enamel formation, individuals would not have had to travel far, if at all. Furthermore, it is unlikely that the settlements for the cemeteries were found at the same altitude. It is known from an archaeological context that settlement patterns changed during the transition from the Late Bronze Age to the Early Iron Age, with upland settlements becoming more common. This would have influenced $\delta^{18}O_{carb}$ values, as Vreča et al. (2006) were able to calculate an altitude effect of -0.28‰ per 100m for continental Slovenia.

Seasonality and variation in climate

The combination of the environmental factors already described in Section 8.2 could have resulted in the broad range of $\delta^{18}O_{carb}$ values produced by the ENTRANS project, with ranges up to 3.5‰, within a single cemetery group. The wide range of modern $\delta^{18}O$ values from precipitation indicate variability may be connected to local fluctuations in climate, based on seasonality throughout the period of enamel formation.

It is difficult to estimate variation in isotope ratios due to mobility versus isotopic change related to normal, seasonal climatic variation. The fact that human activities such as brewing, stewing, boiling and breastfeeding are known to increase $\delta^{18}O_{carb}$ values further complicates this problem (Wright and Schwarcz 1998; Brettell et al. 2012; Britton et al. 2015).

Overall, from utilising this method, the extent to which people were moving around their immediate landscape is unclear. Nevertheless, even though overall interpretations from this dataset need to be made with caution due to a lack of baseline data, what can be said is that no immigrants were identified as coming in from locations characterised by a significantly different climate. However, as demonstrated in Tables 8.11 and 8.12, Oxygen isotope ratios measured from across Europe, including Germany, Croatia, Greece, Italy and Bohemia, have produced delta values that are relatively similar to those obtained as part of this current study. This shows that ranges of oxygen isotope ratios are not geographically distinctive, especially between areas with similar climates. Consequently, when investigating themes of residential mobility other forms of evidence are required to identify non-locals.

Phosphate	
Oelze 2012	**Magdalenenberg SW Germany**
	$\delta^{18}O_p$ VSMOW ‰
Max	**19**
Min	**13.9**
Mean	15.9
Scheeres et al 2014	**Bohemia (females)**
	$\delta^{18}O_p$ VSMOW ‰
Max	**17.3**
Min	**15.5**
Mean	16.5
ENTRANS	**Slovenia and north-east Croatia**
Converted from $\delta^{18}O_{carb}$ VSMOW	$\delta^{18}O_p$ ‰
Max	**16.5**
Min	**10.1**
Range	6.4
Mean	14.3

Table 8.13. A comparison of maximum, minimum and mean $\delta^{18}O_p$ values from different published investigations of oxygen isotope ratios from across Europe. ENTRANS $\delta^{18}O_{carb}$ values have been converted into $\delta^{18}O_p$ values following Chenery et al (2012) for comparison.

Carbonate	
Garvie-lok 2009	**Corinth**
	$\delta^{18}O_{carb}$ VSMOW ‰
Max	**27.7**
Min	**25.4**
Mean	26.3
Prowse et al 2007	**Isla Sacra (Italy)**
Converted from $\delta^{18}O_{carb}$ VPDB	$\delta^{18}O_{carb}$ VSMOW ‰
Max	**28.1**
Min	**22.3**
Range	5.9
Mean	25.7
Prowse et al 2007	**Modern Romans (Pre-industrialised)**
Converted from $\delta^{18}O_{carb}$ VPDB	$\delta^{18}O_{carb}$ VSMOW ‰
Max	**27.6**
Min	**22.8**
Range	4.8
Mean	25.6
Lightfoot 2014	**Croatia - Adriatic coast (Iron Age)**
Converted from $\delta^{18}O_{carb}$ VPDB	$\delta^{18}O_{carb}$ VSMOW ‰
Max	**29.5**
Min	**24.1**
Mean	27.0
Nicholls unpublished	**Samnites**
	$\delta^{18}O_{carb}$ VSMOW ‰
Max	**27.5**
Min	**25.3**
Mean	26.0
ENTRANS	*Slovenia and north-east Croatia*
	$\delta^{18}O_{carb}$ VSMOW ‰
Max	*25.3*
Min	**19.1**
Mean	23.3

Table 8.14. A comparison of maximum, minimum and mean $\delta^{18}O_{carb}$ values from different published investigations of oxygen isotope ratios from across Europe. It has been indicated where values have been converted from $\delta^{18}O_{carb}$VPDB to $\delta^{18}O_{carb}$ VSMOW using Coplen (1988)

8.8 Oxygen isotope ratios, age at death, and sex at Križna gora

As has already been discussed elsewhere in the thesis, sex and age at death have not been observed to be obviously correlated with the isotopic results. In Section 6.5.2 a potential trend was identified between enamel carbonate ratios and biological sex at Križna gora. Here, a small group of females were observed to exhibit higher $\delta^{13}C_{carb}$ values than the rest of the cemetery group.

This would indicate that this group of females was consuming a higher quantity of C4 based non-proteins, relative to the rest of the sample (Kellner and Schoeninger 2007; Froehle et al. 2010). However, this was argued to be a tenuous interpretation given the small sample size and the otherwise relatively homogenous clustering of both males and females.

Other than this, carbon and nitrogen isotope results have suggested that communities inhabiting Late Bronze Age and Early Iron Age Slovenia and north-eastern Croatia were following a relatively homogenous diet, which was not dictated by age or sex. Some variability was noted in the later increments of tooth dentine, which would represent a diet post weaning. This variability could be referencing periods of seasonal variation in diet, but there was no evidence to suggest that individuals were consuming diets based on their biological characteristics, i.e. age or sex.

Non-adults sampled as part of this study have revealed some isotopic variation in their carbon and nitrogen isotope ratios, but this is largely restricted to the first couple of years of life, covering important life phases of breastfeeding, weaning and a normalisation of diet to that of the rest of the population. This is also reflected above in Section 8.6, where differences in $\delta^{18}O_{carb}$ values between deciduous and permanent teeth could be tracking the shift from breast milk to the ingestion of other water sources (Wright and Schwarcz 1998; Wright and Schwarcz 1999).

The following section of the chapter investigates relationships between oxygen isotope ratios and themes of biological sex and age at death. Križna gora was selected for this investigation because of the isotopic sample size and the quality of age and sex data available in comparison to other cemeteries. Additional information regarding the individuals where tooth enamel was sampled for oxygen isotope analysis can be found in Table 8.13.

Identifier (n=25)	*Sex*	*Age range*
KG 2	F?	Young adult
KG 7	?	Middle adult
KG 22	F?	Middle adult
KG 30	M?	Mature Adult
KG 32	F?	Young adult
KG 57	?	Middle adult
KG 59	N/A	Non-adult
KG 62	F?	Adult
KG 63	F?	Middle adult
KG 65	M?	Young adult
KG 67	M?	Middle adult
KG 70	M?	Young adult
KG 72	F?	Young adult
KG 75A	N/A	Non-adult
KG 75B	N/A	Non-adult
KG 76	M	Young adult
KG 77	M?	Middle adult
KG 79	?	Young adult
KG 81	F?	Young adult
KG 83	M?	Middle adult
KG 84	M?	Middle adult
KG 85	?	Middle adult
KG 103	?	Adult
KG 124	N/A	Non-adult
KG 129	?	Middle adult

Table 8.15. Additional information regarding individuals sampled for oxygen isotope analysis, including sex and age at death.

As has already been discussed in Chapter 4 on the osteological analysis of this site, the preservation of the remains was not good and so most sex assessments have been made at the ‘probable’ female/male level. However, for this preliminary exploration, comparing isotope values and biological characteristics, this has been deemed as acceptable.

8.8.1 Age at death

Oxygen isotope ratios have been separated into age at death categories of young adult (n=8), middle adult (n=10), mature adult (n=1), adult (n=2) and non-adult (n=4 plus the $\delta^{18}O_{carb}$ value of the second tooth from KG 75) have been presented in Figure 8.12, and Tables 8.16 and 8.17.

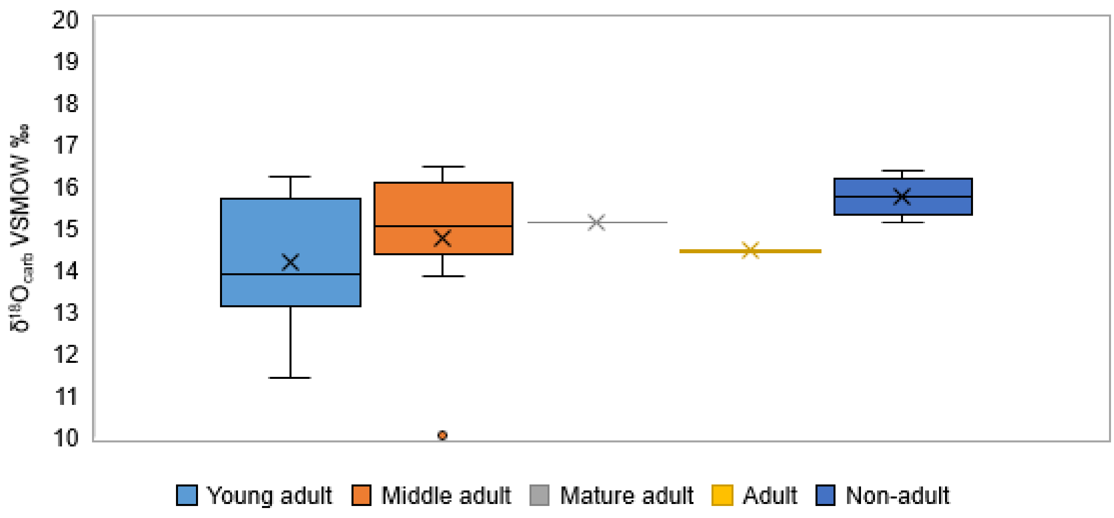

Figure 8.12. Box and whisker plot comparing $\delta^{18}O_{carb}$ values separated into age at death categories. An increased level of variation can be observed in the young adult category, relative to the other categories.

The largest spread of results can be observed in the young adult category, followed by the middle adult category. This can be observed in both their interquartile ranges (Table 8.16) and in the length of the whiskers on the plot. When the mean and median values are observed (Table 8.17), these are relatively similar between the age categories, varying between -9.5‰ and -11.9‰, and between -9.5‰ and -12.3‰ respectively. Even so, when the young adult group is considered, half of the data for this category plots lower than that of the whole (except for one outlier) middle adult category. The remaining mature adult, adult and non-adult data plots within the interquartile range of the middle adult data, suggesting that there is little variability between the groups.

	Q1 ($\delta^{18}O_{carb}$‰)	Q3 ($\delta^{18}O_{carb}$‰)
Young adult	15.7	13.2
IQR	2.5	
Middle adult	16.1	14.4
IQR	1.7	
Mature adult	24.1	24.1
IQR	0	
Adult	23.4	23.4
IQR	0	
Non-adult	16.2	15.3
IQR	0.9	

Table 8.16. First quartile values, third quartile values, and Interquartile ranges of $\delta^{18}O_{carb}$ values of age at death categories

		$\delta^{18}O_{carb}$‰
Young adult	Median	22.9
	Mean	23.1
Middle adult	Median	24.0
	Mean	23.7
Mature adult	Median	24.1
	Mean	24.1
Adult	Median	23.4
	Mean	23.4
Non-adult	Median	24.6
	Mean	24.7

Table 8.17. Mean and Median $\delta^{18}O_{carb}$ values of age at death categories

This trend could be reflecting the inconsistencies in sample sizes between age categories, as none of them is large enough to be representative. With such small sample sizes, a $\delta^{18}O_{carb}$ value from a single individual could be having a significant influence on how these categories are presenting themselves. This is the most likely explanation for the increased spread of points seen in the young adult category in relation to the other groups.

Overall, there is very little evidence to suggest that there is any relationship between $\delta^{18}O_{carb}$ values and age at death. This is probably linked to the type of tissue sampled. As the enamel carbonate was selected for analysis, the $\delta^{18}O_{carb}$ values presented here are only reflecting the isotopic composition of liquids ingested while the enamel was forming. For this reason, any changes in the $\delta^{18}O$ values of liquids consumed after this time will have had no effect on $\delta^{18}O_{carb}$ values collected as part of this study. To investigate whether $\delta^{18}O_{carb}$ values varied among different age groups the bone apatite could be sampled instead, as this remodels with time and would subsequently provide an isotope value influenced by changes in the isotopic composition of liquids consumed (Kellner and Schoeninger 2007; Froehle et al. 2010; Britton et al. 2015).

Even though there are heavy limitations on the examination of oxygen isotope analysis in relation to age at death, perhaps it is possible to explore other relationships between $\delta^{18}O_{carb}$ values and biological characteristics, such as biological sex.

8.8.2 Sex

In contrast to age at death, the examination of a relationship between oxygen isotope ratios and sex could be more fruitful. This is primarily because the sex (not necessarily gender) of an individual does not alter with time. Any discrepancies in the oxygen isotope ratios between the sexes could be linked to sex-based mobility and other cultural practices, such as the longevity of breastfeeding.

In Figure 8.13, $\delta^{18}O_{carb}$ values have been split into categories of female (n=12), male (n=8), and non-adult, which were not included in the osteological analysis for sex assessment (n=4). Here, it can be observed that the female category has the largest spread of values and, additionally, that roughly three-quarters of the data in this category plot lower than the other groups. The data making up the male category has plotted in line with that of the non-adult category.

When the mean $\delta^{18}O_{carb}$ values, found in Table 8.18, are compared, the female group has a mean value 1.6‰ lower than that of the male category. This difference is larger still between the female and non-adult data (1.9‰). The interquartile ranges for the female, male and non-adult data is very similar, suggesting the female data is systematically lower than the other two categories. Additionally, following a Kruskal-Wallis ANOVA test, a significant difference was identified between male and female oxygen isotope ratios (See Figure 8.14). Although this is a very small dataset, these results suggest that there is an increased variability seen within the female data relative to that of other sex-based categories.

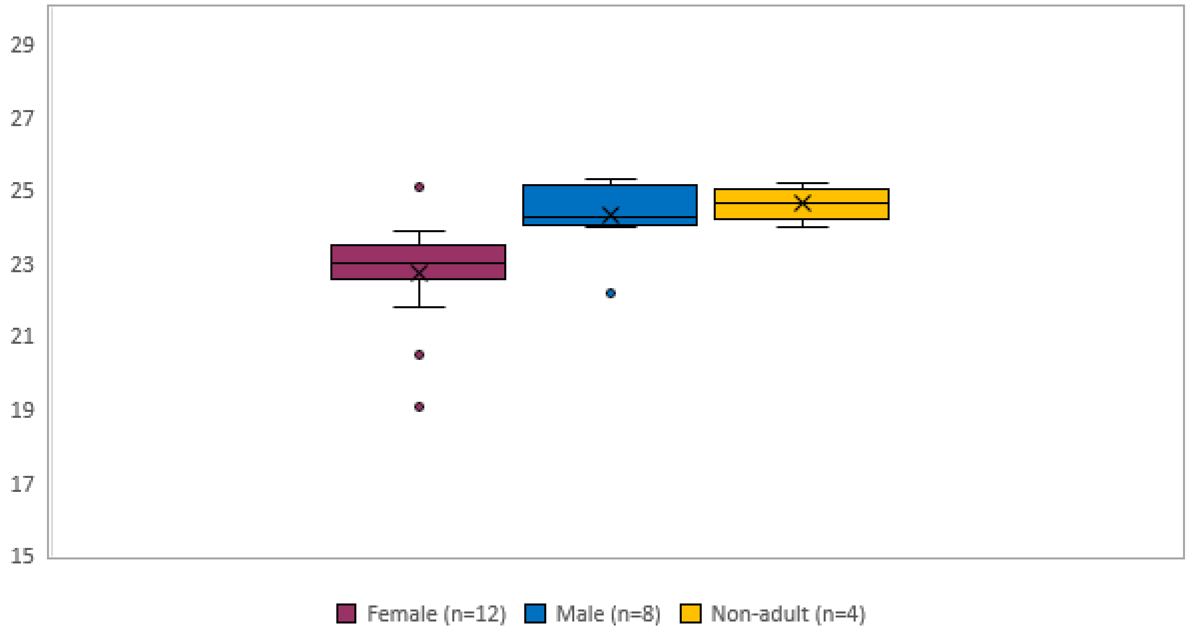

Figure 8.13. Box and whisker plot comparing $\delta^{18}O_{carb}$ values from individuals buried at Križna gora, separated into sex-based categories. An increased level of variation can be observed in the female category, relative to male and non-adult categories.

δ^{18}O VSMOW ‰	Mean	Standard deviation	Q1	Q3	IQR
Female (n=12)	22.7	1.6	23.5	22.6	0.9
Male (n=8)	24.3	1.0	25.2	24.1	1.1
Non-adult (n=4)	24.6	0.6	25.1	24.2	0.9

Table 8.18. Mean and Median $\delta^{18}O_{carb}$ values of age and sex-based categories

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Oxygen is the same across categories of Sex.	Independent-Samples Kruskal-Wallis Test	.008	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure 8.14 The results of a Kruskal-Wallis test for significant differences in the distribution of male and female Oxygen isotope ratios

As has already been discussed, variability within the sex-based data was also interpreted from the enamel carbonate results in Chapter 6. As this has also been identified in the oxygen isotope ratios, the two isotopes have been combined in Figure 8.15, with the sex of the individuals also indicated to investigate whether isotopic variability is occurring in the same individuals during the period of enamel formation.

Once plotted, the male data is observed to cluster relatively tightly (with one outlier: KG 65), while the female data is much more dispersed, both on the x and y-axes. However, females exhibiting dissimilar $\delta^{18}O_{carb}$ values are not necessarily the same individuals that were seen to produce anomalous $\delta^{13}C_{carb}$ values in Chapter 6. Some of the females with recognisably different $\delta^{18}O_{carb}$ values are observed to have similar $\delta^{13}C_{carb}$ values as the males and vice versa. One notable exception to this is KG 22, where both of their $\delta^{18}O_{carb}$ and $\delta^{13}C_{carb}$ values appear to diverge from the male cluster of points. This individual has already been identified as an outlier to the whole Slovenian data set and a possible non-local.

It must be reiterated that this is a very restrictive sample and that more work into sex-based and other social distinctions based on biological characteristics are required to form any solid conclusions. However, this data does suggest that this may be a fruitful line of enquiry for future research, with larger sample sizes with good quality osteological data.

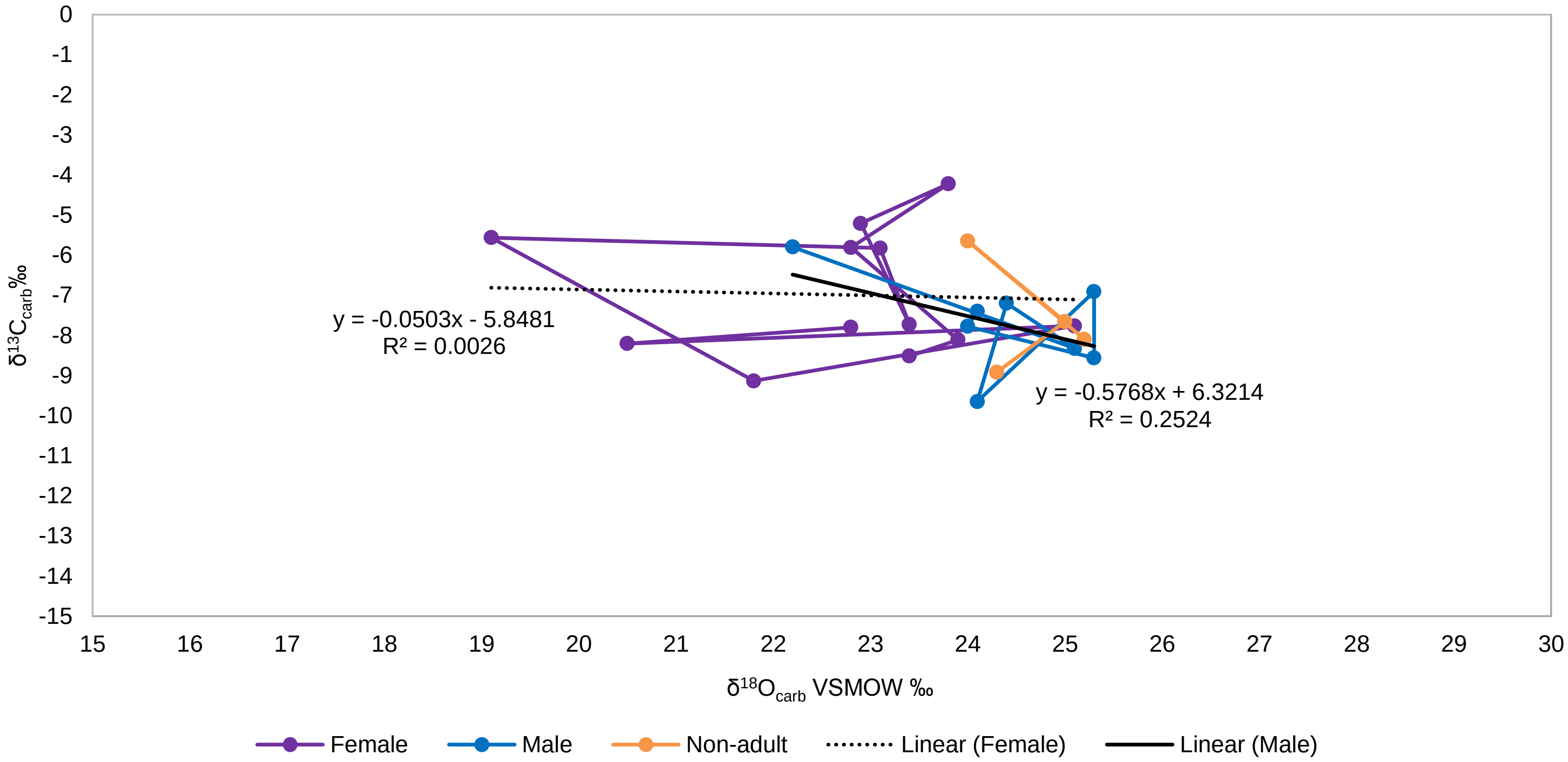

Figure 8.15. $\delta^{13}C_{carb}$ and $\delta^{18}O_{carb}$ plot with isotope ratios separated into sex-based categories, including Non-adult, where sex assessment was not carried out. The lines have been used to further illustrate the spread of data observable between categories. The plot shows the slight distinction between Male and Female data, with roughly half of the female $\delta^{13}C_{carb}$ values plotting above the Male $\delta^{13}C_{carb}$ values. Similarly, almost all of the Female $\delta^{18}O_{carb}$ values plot above (to the left) of the Male data. However, there appears to be little correlation between anomalous Female $\delta^{18}O_{carb}$ and $\delta^{13}C_{carb}$ values. This indicates that there is no relationship between females with high enamel carbonates isotope ratios related to higher C4 plant protein consumption, and females with higher Oxygen isotope ratios linked with potential variable water sources. It can, therefore, be argued that the isotopic variation between Male and Female categories, seen in these two isotopic datasets, is the result of different and distinct phenomena.

8.9 Summary of oxygen isotope analysis

Overall, there is a clear discrepancy between the mean $\delta^{18}O$ values of modern precipitation and $\delta^{18}O_{dw}$ estimates calculated from the $\delta^{18}O_{carb}$. This could be due to a few factors, including climatic variation or the procurement of water from different sources. It is more likely that the incongruity is linked to errors introduced when converting $\delta^{18}O_{carb}$ to $\delta^{18}O_{dw}$ values and inter-laboratory variability in measured results (Pollard et al. 2011; Pestle et al. 2014). As similar interpretations can be drawn from both the $\delta^{18}O_{carb}$ and $\delta^{18}O_{dw}$ estimations, it does appear that converted values are still displaying reliable trends. However, as the attribution of geographical location was not the main aim of this investigation, $\delta^{18}O_{dw}$ values were found to be less useful than the original $\delta^{18}O_{carb}$ values, which display less error and arguably are more reliable for the exploration of homogeneity and heterogeneity within communities at different scales.

Only two individuals were identified as outliers: Križna gora graves 22 and 32. A pilot study into the application of strontium isotope analysis is presented in Chapter 9, which includes the individual buried in Grave 32. The use of this method could help to elucidate whether this individual is a non-local.

Shifts in isotope ratios observed between deciduous and permanent teeth could support the interpretation (based on the carbon and nitrogen isotope analyses) that the onset of weaning for these individuals occurred prior to the age of 3.5 years, or before the crown was fully mineralised. This has been evidenced by the movement from higher to lower $\delta^{18}O_{carb}$ values between the deciduous and permanent teeth of the same individual, suggesting a shift in the relative importance of ^{18}O enriched breast milk and the more ^{18}O depleted local drinking water (Wright and Schwarcz 1998; Britton et al. 2015). It is not known if the consumption of breast milk had ceased during enamel formation, or at what time. If this is a cause for isotopic variation between deciduous and permanent teeth, it is difficult to tell as to what magnitude this might be influencing the data and, subsequently, contributing to the variability seen in these data sets. For this reason, the investigation into possible mobility practices should not include interpretations based on the $\delta^{18}O_{carb}$ values of deciduous teeth.

The relatively broad ranges in $\delta^{18}O_{carb}$ values observed from across this study area, most obvious from the data from Križna gora because of sample number, is probably because of the variable local landscape and climate. The cemeteries may have served more than one community, with people drinking water from a number of sources. These may have included standing water and wells, as well as rivers and water from either uplands or lowlands. Coupled with the complex climatic systems that have been shown to cause isotopic variation of up to 19‰ in modern precipitation samples over a period of three years, this range of up to 3.5‰ (or even up to 6.2‰ if the Križna gora outliers are also included) in $\delta^{18}O_{carb}$ values appears reasonable.

Even though the use of oxygen isotope analysis has not revealed whether communities were mobile between one another ($\delta^{18}O_{carb}$ values from different cemeteries are relatively similar and tend to overlap), there is also no evidence to suggest that individuals travelling from further afield were buried at these sites. To test this hypothesis further, a larger data set would be required.

Overall, in terms of investigating residential mobility, communities seem to be quite homogenous. However, when communities are broken down into biologically based categories, such as sex, these analyses have highlighted some potential variability. The use of oxygen isotope analysis on enamel carbonate has illustrated that there is a higher variability in the isotope ratios produced by females, relative to males. This supports the interpretations made in previous chapters that diet and lifestyle may not have been as homogenous as originally thought from the use of bulk collagen analysis alone.

Chapter 9 Strontium Isotope Analysis: Pilot Study

This section of the thesis will present the results of a pilot investigation into strontium isotope analysis, sampling individuals from two cemeteries: Dolge njive (n=8) and Križna gora (n=7). These sites were chosen based on the number of teeth available from a single site. The archaeological context of these cemeteries is also relatively reliable, unlike, for example, Obrežje where the context of the graves is questionable. The location and local geology of these two cemeteries are presented in Figure 9.1.

This method is commonly utilised for the identification of non-locals (Evans et al. 2006; Montgomery 2010; Evans et al. 2012). Strontium isotope analysis was completed under the supervision of Dr Janet Montgomery at the University of Durham. As has already been discussed in Chapter 6, the diet of those buried at Križna gora and Dolge njive is comparable, with a heavy reliance of C4 and C3 plants, as well as terrestrial, herbivorous animal protein. The oxygen isotope analysis produced isotope ratios consistent with the climate and environment of Slovenia, though it was also shown that much of temperate Europe could produce similar ranges of $\delta^{18}O$ (Sections 8.2 and 8.7). Consequently, the argument for mobility could not be proven or disproven using this method of investigation.

Two individuals were identified as being potential non-locals from the Križna gora dataset (Graves 22 and 32) because of their anomalous $\delta^{18}O_{carb}$ values, which fell outside of 2 standard deviations from both the cemetery and whole ENTRANS data set mean values. Unfortunately, only one of these individuals (32) was included in the strontium isotope pilot study, as the other had insufficient dentition. However, the strontium isotope ratios of the individual buried in Grave 32 may help to elucidate whether this person was a non-local, or if their unusual $\delta^{18}O_{carb}$ value was the result of other factors.

The results of strontium isotope analysis can be found in Table 9.1 and in Figures 9.2, 9.3, 9.4 and 9.6. $^{87}Sr/^{86}Sr$ values have been plotted against $\delta^{18}O_{carb}$ values to investigate the relationship between the two isotope ratios.

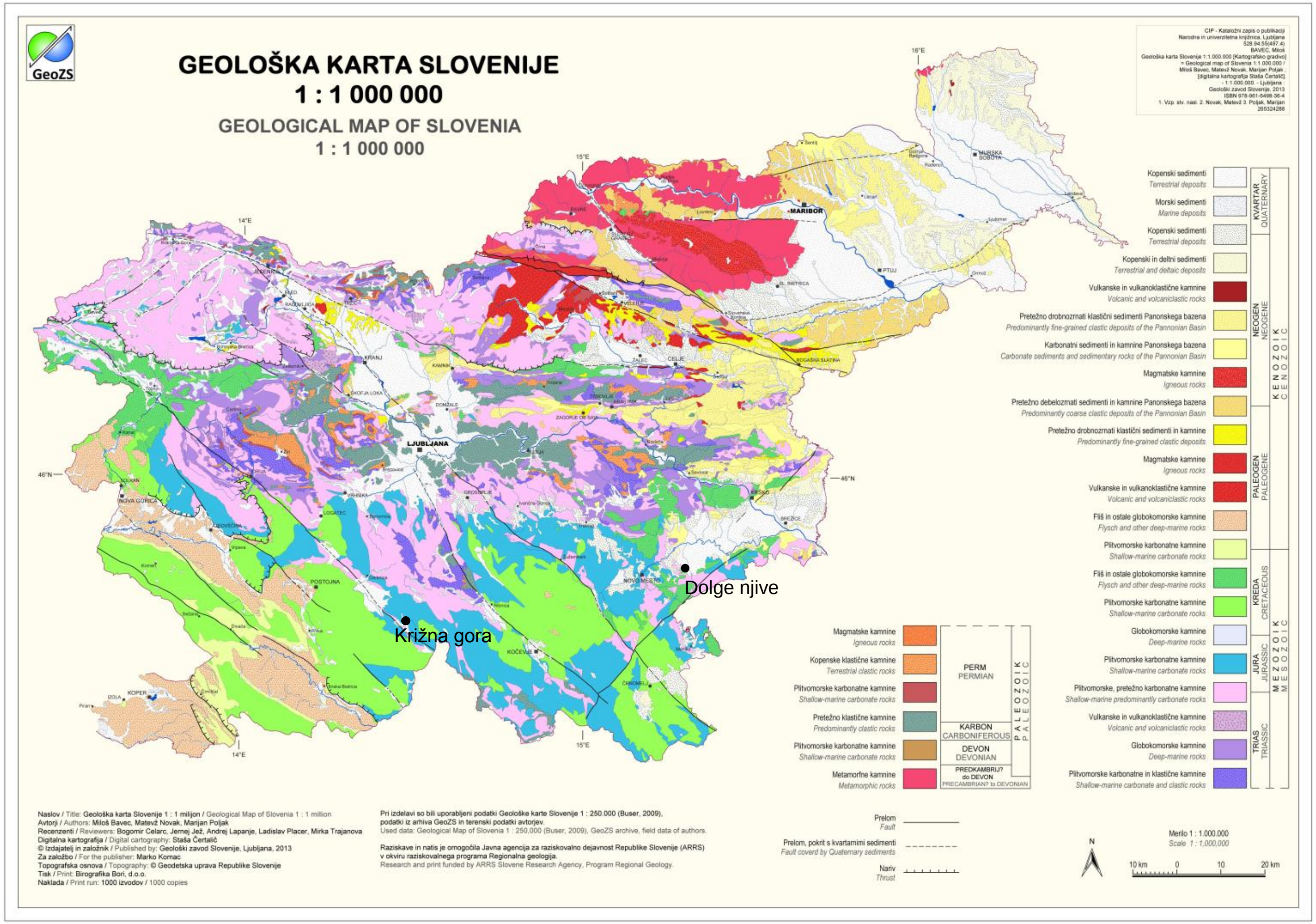

Figure 9.1. Geological map of Slovenia. Adapted from Buser (Buser 2009) (2009). (Geološi Zavod Slovenije: http://prenit.geo-zs.si/geozs/index.php/en/?option=com_content&view=article&id=233 Accessed 12/4/18)

Križna gora	$\delta^{18}O_{carb}$ VSMOW ‰	$^{87}Sr/^{86}Sr$ norm	Sr concentration
KG 32	20.5	0.708932	63
KG 59	24.3	0.708904	73
KG 76	24.4	0.708989	63
KG 81	21.8	0.708918	47
KG 84	24.0	0.708952	82
KG 124	25.2	0.709065	75
KG 129	25.3	0.708976	68
Dolge njive			
DN 1775	22.3	0.70948875	135
DN 1781	22.0	0.70973775	165
DN 2603	22.8	0.71002875	59
DN 2604	21.8	0.71000375	121
DN 2680	22.2	0.71016575	86
DN 2903	22.9	0.70960075	100
DN 2359	24.3	0.70910375	283
DN 2900	21.1	0.70924175	226

Table 9.1. $^{87}Sr/^{86}Sr$ values and strontium concentrations, including data from Dolge njive (n=8) and Križna gora (n=7).

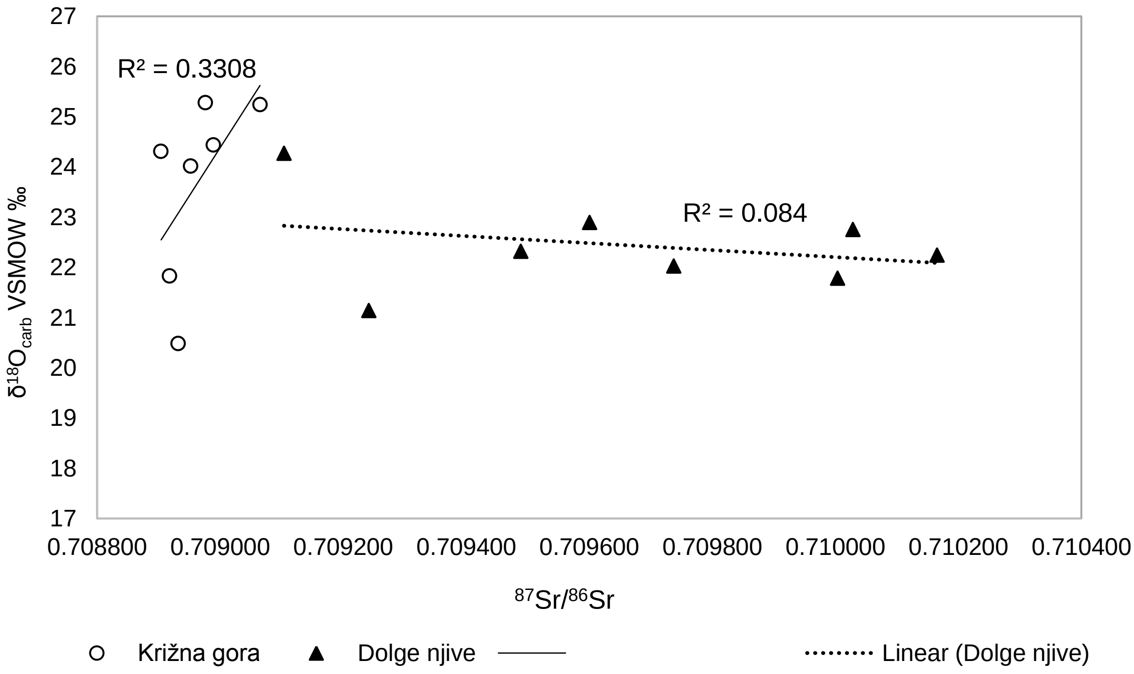

Figure 9.2. A plot of $^{87}Sr/^{86}Sr$ and $\delta^{18}O_{carb}$ VSMOW values, including data from Dolge njive (n=8) and Križna gora (n=7)

In a similar way to which the oxygen isotope analysis was approached, strontium isotope analysis was not used as a means of linking individuals to particular geographical locations. The aim of this pilot study was to explore potential $^{85}Sr/^{86}Sr$ values from the study area and any possible trends. No environmental samples, such as water or plants, were taken, nor have any animal samples been analysed. For this reason, there is no reference to a predicted isotope ratio of biologically available strontium for the areas surrounding these two cemeteries. Previous investigations into communities settled on chalk and limestone based geologies have produced $^{87}Sr/^{86}Sr$ values of around 0.706 to 0.709 (Evans et al. 2006; Evans et al. 2012), while more radiogenic rocks would be expected to produce $^{87}Sr/^{86}Sr$ values of up to 0.72 (Evans et al. 2006).

9.1 Site based interpretations

9.1.1 Križna gora

The Strontium isotope ratios obtained from seven individuals buried at Križna gora have been presented in Table 9.1 and in Figure 9.3.

$^{86}Sr/^{87}Sr$ values were observed to cluster closely between 0.708904 and 0.708976, with strontium concentrations varying between 63 and 82. The sample taken from the individual buried in grave 32 has produced an $^{86}Sr/^{87}Sr$ value of 0.708932, with a concentration of 63. These values corroborate well with the rest of this small group of isotope ratios. The results of this analysis, therefore, do not support the hypothesis put forward from the oxygen isotope results that this person was a non-local.

Overall, the tight clustering of data points suggests that this small group of individuals were consuming food produced in a similar location, with the same mix of biologically available strontium. $^{87}Sr/^{86}Sr$ values of c.0.708 are consistent with a chalk or limestone geology, which matches the location of the cemetery (Evans et al. 2006; Evans et al. 2012). These results indicate that the food consumed by those buried at Križna gora was grown in an area high in calcium carbonates (Evans et al. 2006). The $\delta^{18}O_{carb}$ values are more variable relative to their strontium isotope values, which could suggest that this latter inconsistency is related to factors other than mobility, such as climate, or variation in local water sources.

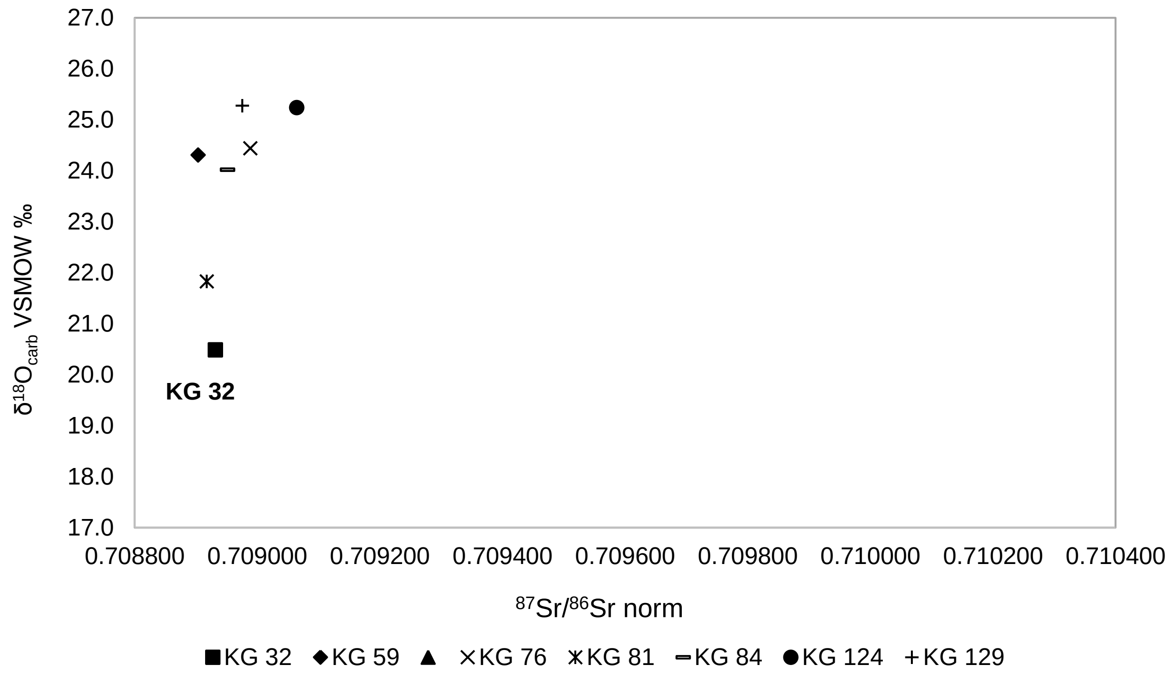

Figure 9.3. $^{87}Sr/^{86}Sr$ and $\delta^{18}O_{carb}$ (VSMOW) plot for Križna gora (n=7)

9.1.2 Dolge njive

The results of strontium isotope analysis on individuals buried at Dolge njive can be found in Table 9.1 and Figure 9.4. In contrast to the Križna gora data, the results obtained from the Dolge njive sample are far more variable, with $^{86}Sr/^{87}Sr$ ranging from 0.70910375 to 0.71016575, and strontium concentrations from 59 to 283. This linear spread of data, between two distinct endpoints, could be reflecting the movement of resources or people between two locations with distinctive biologically available strontium values (Montgomery 2010). This would be reflected in the data as a spread of isotope ratios between two extremes, with data points spread between these two extremes (Montgomery 2010). This is because strontium isotope ratios are the result of the averaging of all biologically available strontium consumed and incorporated during the period of enamel mineralisation (Bentley 2006). If an individual was moving between two isotopically distinct locations and consuming food grown within these areas, then their isotope ratios would reflect a mixture of these two strontium sources. Another explanation would be that the food was being produced in two isotopically distinct locations and subsequently transported to these people (potentially at the Vinji vrh hillfort), then consumed.

The area surrounding the cemetery is geologically complex. If these people inhabited the hillfort, at least 4 different geological formations surrounded them. These include marls, sandstones and quartzite marls (Miocene Age); limestones and calcirudite (Miocene Age); coarse-grained dolomite (Triassic); other marls and limestones (Cretaceous) (P. Mason pers comm. 2017)

There are also Quaternary and Holocene clay deposits to the south of the barrows in the Dolge njive area itself, derived from erosion products from the Triassic and Cretaceous deposits (as above) in the Bela Cerkev and Draga areas. The Dolge njive barrows themselves were constructed on calcareous marl, in an area which was fluvially active in the early Holocene (P. Mason pers comm. 2017).

The investigation of $\delta^{18}O_{carb}$ values did not provide any evidence for residential mobility with regards to the individuals buried at Dolge njive, as results were relatively homogenous. This would suggest that, if these individuals were involved in something like transhumance, this was not affecting their oxygen isotope ratios. Therefore, it would probably have to have been horizontal, rather than vertical transhumance. Conversely, as the geology of the immediate area is so geologically diverse, $^{86}Sr/^{87}Sr$ values obtained for individuals buried at Dolge njive is probably an average of the isotope ratios consistent with these bedrocks and deposits. Without any baseline data investigating potential, local values of biologically available strontium (e.g. from plant, water, soil or archaeological bone/ tooth enamel samples), it is difficult to speculate further regarding these results. The $^{86}Sr/^{87}Sr$ values of 0.709 – 0.7101 are higher than might be expected from chalk or limestone geologies, and may have been influenced by the fluvial deposits, or could indicate resources coming from further afield (Bentley and Knipper 2005; Evans et al. 2006; Montgomery et al. 2007; Montgomery 2010).

The results from Dolge njive are further complicated when the results of aDNA analysis are considered. These results have identified the three young adults buried in Graves 1775, 2603 and 2680 as siblings (one sister and two brothers). These individuals have been indicated in Figure 9.5. As can be observed, although the strontium isotope ratios for Dolge njive 2603 and 2680 are quite similar, the ratio for Dolge njive 1775 (the sister) is quite different. This could suggest that the two brothers and the sister were raised in different locations, or that they were consuming different resources, with variable strontium isotope ratios.

To explore these differences further, the carbon and nitrogen isotope ratios for these individuals have been revisited in Figure 9.5. This Figure shows an increased isotopic variability in the carbon isotope ratios of the individual buried in Grave 2680, relative to 1775 and 2680. This spread of data (dentine-rib -2.7‰; rib-long bone +1.6‰; dentine-long bone -1.1‰) indicates the variable consumption of C4 plants (millet) throughout the life course of this individual. Unfortunately, all three skeletal elements (dentine, rib and long bone) were not available for the other two siblings. However, there appears to be a similar shift (-0.9‰) in the carbon isotope ratios between the apex dentine and long bone samples taken from Dolge njive 1775 to that of Dolge njive 2680. Conversely, there is little similarity between the carbon isotopic variability (+0.3‰) seen from Dolge njive 2680 and Dolge njive 2603. However, when the apex dentine sample from Dolge njive 2680 (which is an outlier for the cemetery group as a whole) is removed, there is little observable difference in the carbon and nitrogen isotope ratios between these siblings, or between the siblings and the remainder of the cemetery group. This is evidence to suggest that all three siblings were consuming a similar diet for most of their lifetime. The differences observed in the strontium isotope ratios between the two brothers and the sister either the result of spending their early childhood in different locations or consuming different foods produced on different geologies.

When the strontium concentrations are also examined, a wide range of values is observable from the individuals buried at Dolge njive, between 59ppm and 283ppm. This is a significantly larger spread of data than that of the individuals buried at Križna gora of between 47ppm and 82ppm. It has been argued that the strontium concentration of an archaeological sample can indicate the trophic level of food consumed by an individual (Evans et al. 2006). It is believed that strontium concentrations decrease with increasing trophic level (Evans et al. 2006). Therefore, individuals consuming higher quantities of meat and dairy would have a lower strontium concentration value than a person eating a larger quantity of plants. For example, Evens and colleagues have quoted an average value of 51.6 +/- 16ppm for a sample of modern Britain's (Evans et al. 2006). As the tooth enamel was sampled for this analysis, only food consumed during the formation of the tooth crown (early childhood) would have influenced this value.

Using this hypothesis, the strontium concentrations of individuals buried at Križna gora are very similar, indicating that these people were probably sharing a similar diet. The values collected from Dolge njive, however, provide a different trend. In a similar trend to the $^{86}Sr/^{87}Sr$ values, the data is spread out in a linear pattern. This suggests that there was a variable consumption of different trophic level foods, with some eating more meat/dairy than others.

When the three siblings previously identified through aDNA analysis are highlighted, as has been done in Figure 9.6, the three individuals are once again separated. The two brothers have the highest strontium concentrations of the Dolge njive data set (2603: 59ppm; 2680: 86ppm), while the sister has a relatively higher strontium concentration of 135ppm. If the quoted value for modern Britain's of 51.6 +/-16ppm is used in this scenario, the two brothers appear to have been consuming a similar quantity of meat and dairy (Evans et al. 2006). The sister, on the other hand, along with much of the rest of the individuals from this cemetery, appears to have been eating fewer animal products and more, lower trophic level food. Furthermore, returning to the Križna gora data set, the relatively high values of between 47 and 82ppm could suggest a widespread, increased consumption of animal products, in comparison to Dolge njive.

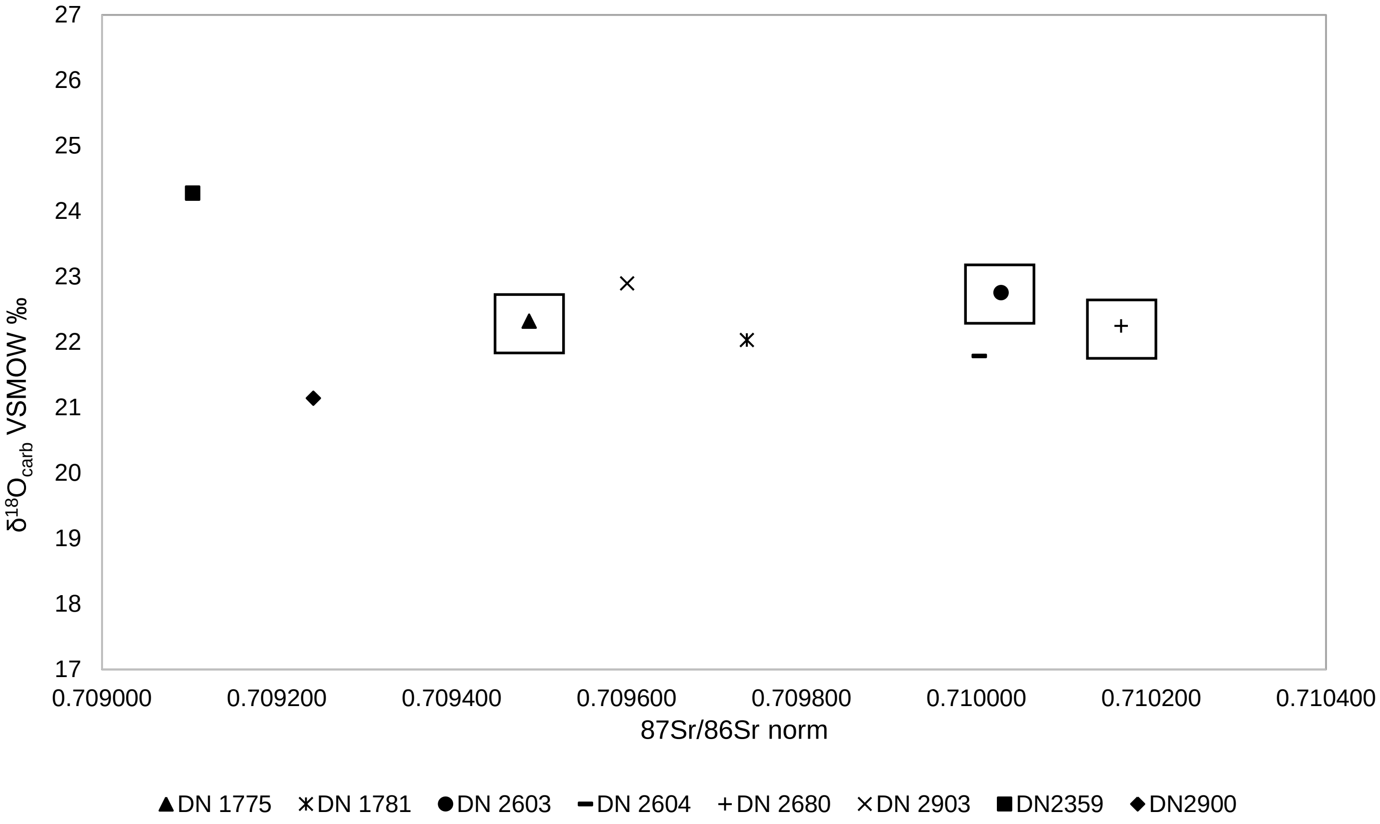

Figure 9.4. $^{87}Sr/^{86}Sr$ and $\delta^{18}O_{carb}$ (VSMOW) plot for Dolge njive (n=8). The three siblings (Graves 1775, 2603 and 2680), which were identified through the application of aDNA analysis, have been highlighted by the three boxes.

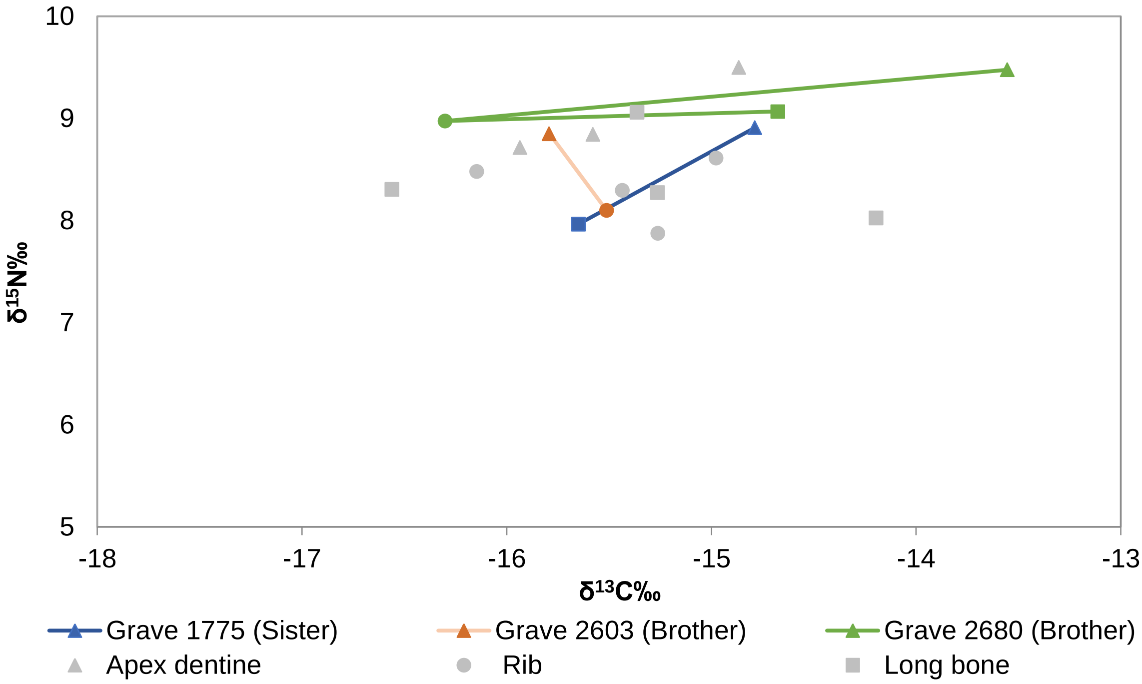

Figure 9.5. Carbon and nitrogen plot for Dolge Njive, with siblings (Graves 1775, 2603 and 2680) highlighted. Triangle = apex dentine; circle = rib; square = long bone. The three skeletal elements for the siblings have been connected to track isotopic change over different periods of development. Isotope ratios for the remaining individuals buried at Dolge njive have been included (in grey) for reference.

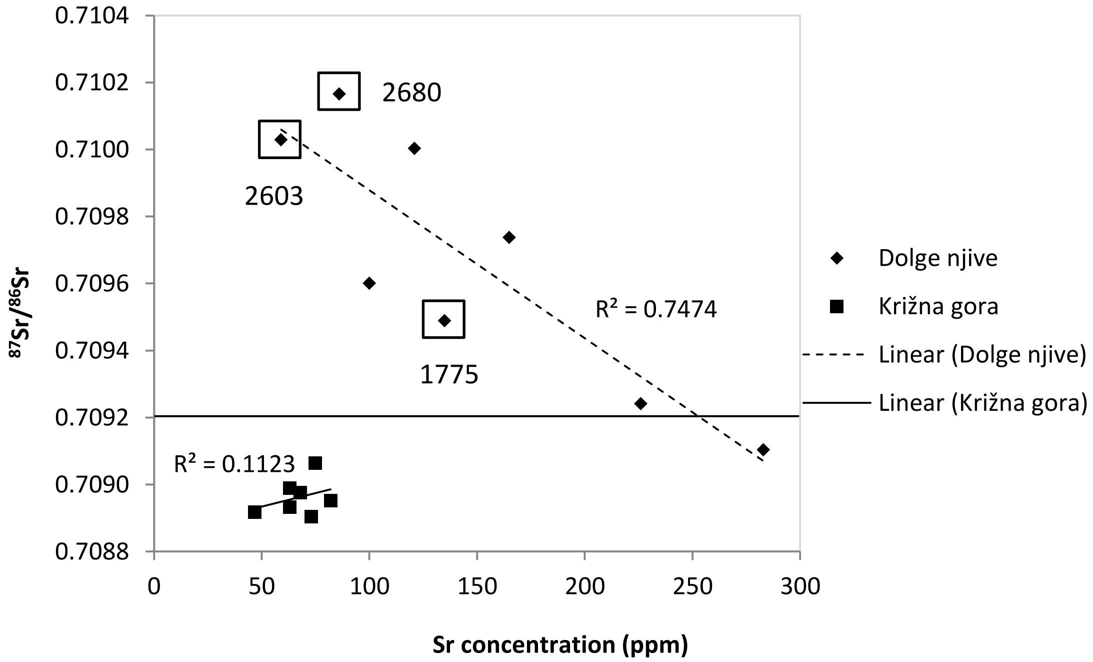

Figure 9.6. A plot of $^{87}Sr/^{86}Sr$ and strontium concentration for Dolge njive (n=8) and Križna gora (n=7). The boxes indicate the three siblings identified via aDNA analysis: two brothers (2603; 2680) and one sister (1775).

9.2 Overview of strontium isotope analysis

Although it has not been possible to explore these results in any great depth because of the lack of contextual information, there are some basic observations that can be made from this data.

Firstly, the groups sampled from these two cemeteries have produced results with notably different trends. The results from Križna gora are suggestive of a sedentary group of individuals, which is also evidence to suggest that the potential non-local (Grave 32) does originate from the same location as the others buried at this cemetery. The group sampled from Dolge njive, on the other hand, is suggestive of a different strategy, with possible movement of people or resources between two distinctive locations. Alternatively, this cemetery may have included individuals from different settlement sites.

Although no definitive interpretations have been made from this small data set, the distinctive differences in strontium isotope ratios and concentrations observed between these two groups suggest that this method is a viable technique for the investigation of heterogeneity/homogeneity in this region.

Chapter 10 Part 1: Death and the Body

“Archaeologists cannot dig up funerals, only the deposits resulting from their terminating practices.”

(Parker Pearson 1999: 49)

The study of funerary archaeology centres on a very specific event – the disposal of a body. This event draws upon different strands of cultural convention such as memory, local cosmology, and shared beliefs (Graham 2009; Oestigaard 2013; Williams 2013). The following chapter discusses the results of osteological analysis under the overarching themes of homogeneity and heterogeneity to further explore how the communities inhabiting the ENTRANS study area treated their dead. This is approached via the consideration of demography, funerary rite (cremation and inhumation) and archaeological context. Throughout this chapter, osteological results shall be discussed in relation to interpretations made previous to this investigation, regarding the funerary archaeology of this study area.

Throughout the transition into the Early Iron Age and beyond, it could be argued that funerary rites and practices continued to evolve across the ENTRANS study area (Teržan 1999; Dular and Tecco-Hvala 2007: 129-131; Mason 2009; Črešnar 2010; Frie 2012). This has been attributed to changing attitudes towards social structure and an increase in ideas flowing through social and economic networks (Potrebica 2008; Črešnar 2010; Dizdar 2013; Potrebica 2016). In comparison, the Late Bronze Age funerary activity appears to have been relatively static, with the Urnfield culture (with regional expressions) dominating large spatial and temporal areas (Teržan 1999). This former rite has been interpreted as reflecting a less complex social structure relative to the Early Iron Age (Mason 1996: 12-14; Križ et al. 2009: 108-111; Črešnar 2010). Progressively, cremation graves are replaced by the inhumation burial rite in some regions, particularly the Dolenjska region of Slovenia (Križ et al. 2009; Mason 2009; Mason and Mlekuž 2016).

It has been argued that this adoption of the Inhumation rite allowed for the increased display of hierarchy, social stratification and the legitimisation of elite power, of the dead and of those surviving the deceased (Frie 2012; Mason 2013). The contrast between the Late Bronze Age and the Early Iron Age, therefore, would have been a shift in the focus of funerary activity from low level, hereditary elites and the wider community, to that of the individual and specific ‘elites’ and corporate descent groups (Mason 1996; Frie 2012; Mason 2013).

This may have been the case, but it is important to remember that both the inhumation and cremation funerary rites were drawn out processes, likely with opportunities at multiple stages for addressing and reflecting the deceased’s individuality and place within their community at the time of their death (Williams 2004; Quinn et al. 2014: 13-16; Williams 2015: 261). To those witnessing these events, symbolism and meaning would have been attributed throughout these processes, not just linked with the final deposits uncovered by archaeologists (Quinn et al. 2014: 13-16). As McKinley (2006) argues, the lack of thorough analysis of the burnt remains themselves has led to the probable underrepresentation of pyre goods and that, by focussing on the grave goods alone, evidence of the multifaceted nature of the cremation rite tends to be overlooked. She further argues that the *“archaeologist sees the minimum, but the picture which emerges from this data is not of a rite less palpably wealthy than that seen in disposal by inhumation.”* McKinley (2006): 83.

10.1 The cremation rite

In the past, the osteological analysis of cremated remains has been somewhat neglected. This is likely because of the increased level of complexity regarding the identification of bone elements, the assessment of sex and the estimation of biological age (see Section 3.1.2 and Chapter 5). The physical changes to the bone, such as fragmentation, warping and shrinkage can make this information difficult, if not impossible, to obtain (McKinley 1993; McKinley 2013). Nevertheless, the assessment of cremated remains from cemetery sights across Slovenia and north-eastern Croatia has provided an insight into the funerary practices of communities living and dying in the Late Bronze Age and Early Iron Age.

The high percentage (30% of graves) of non-adult individuals identified from the Kaptol assemblage was surprising. This site has previously been identified as an elite cemetery for warriors (Šimek 2004; Potrebica and Mokos 2016). This was interpreted from the monumental construction of this cemetery and the presence of high-status grave goods, including horse equipment, weaponry and items of personal adornment (Potrebica and Mokos 2016). The identification of cremated horse remains also indicates high-status individuals, as these animals were probably sacrificed as part of the funeral activities. The high frequency of non-adult remains, particularly in burials such as Tumulus 6, could, therefore, indicate that an elite “warrior” status could be ascribed to individuals who had not yet reached adulthood. Alternatively, the creation of an impressive and highly visible funerary landscape could have been associated with the evolving, competitive society, where funerals could have been a forum for displaying status and power to neighbours, rivals or allies (Hayden 2009; Potrebica and Mokos 2016: 47-48). In this case, the persona of the deceased could have had a lesser importance relative to the living, who may have been working to legitimise their own place within the local and broader social structure (Hayden 2009; Oestigaard 2013).

It is important to note, however, that due to the condition of the bones collected from the Kaptol tumuli, it was not possible to identify multiple burials. Although the mounds seem to have been created for a single use, the remains of more than one individual could have been present, but not identified. Without more detailed knowledge of the site and grave contents, it is difficult to speculate further regarding what was likely a very complex Iron Age funerary practice, specific to this community.

Other differences noted between Bronze Age, Urnfield cemetery assemblages (see Chapter 5) have indicated potential variability in the communal approach to the cremation rite. This was identified when the two Urnfield cemeteries of Kapiteljska njiva and Ljubljana SAZU were compared. These broadly simultaneous cemeteries exhibited differences in both fragment size and bone colour. The lighter, smaller bone fragments observed from the Kapiteljska njiva assemblage gave evidence for a more ‘complete’ cremation of human bodies, relative to that of the Ljubljana SAZU assemblage. This could be indicative of a variation in pyre technology, fuel used, use of coverings/clothing, as well as social approaches and perceptions of the rite itself (McKinley 1994a; Williams 2004; McKinley). The cremation of individuals deposited at Kapiteljska njiva arguably resulted in a more complete ‘transformation’ of the body from corpse to cremated, fragmented bone. This may be reflecting variations in skill or technological understanding, or a difference in the communal expectations (McKinley 1994a; McKinley 2008a; Brück 2014). Furthermore, a more calcined assemblage of cremated remains could be evidence for a high wealth individual or community (Williams 2004; McKinley 2006). Fully calcined skeletal remains indicate high temperatures over a sustained length of time (see Sections 3.1.2 and 5.5). This suggests that those holding the funeral had access to and could afford sufficient fuel, the manpower to collect the fuel, and the specialists to build and sustain the pyre (McKinley 2006).

The following section of this chapter discusses how the cremation funerary rite could have been used to emulate specific aspects of an individual’s persona. Furthermore, how this choice of practice had the potential to affect those witnessing the event.

10.1.2 The cremation rite: burnt into memory

The burning of the body and the subsequent deposition of at least a portion of the burnt remains within cemetery sites was the prominent funerary rite during the Late Bronze Age, continuing into the Early Iron Age in both Slovenia and north-east Croatia (Teržan 1999). In the past, it has been assumed that the prominence of the cremation rite is reflective of a lack of social stratification and, due to the lack of goods deposited with the remains, of less wealthy individuals when compared to those who were inhumed (McKinley 2006). Author’s, such as Williams (2008), have conversely argued that this interpretation does not consider the resources required for the cremation of a body, which in some cases may have been difficult to source (Parker Pearson 1999: 49-50; Williams 2004; McKinley 2006; Williams 2015: 260).

It has also been argued that the practice of cremation and the deposition of burnt remains is unrelated to an individuals’ social status or wealth, and is instead more probably linked to a variation in belief systems, cosmology and the understanding of the world in which these communities inhabited (Parker

Pearson 1999: 49-50; Brück 2014: 119-139; Williams 2014: 93-118). Thus, through the Urnfield type rites, specific constituents of an individuals' persona and identity selected and displayed throughout the funerary process may have differed to those seen in later, more elaborate funerary deposits from the Iron Age. It has been argued that the idea of a bounded individual becomes strengthened during the transition into the Early Iron Age, with the emergence of 'elite' and 'warrior' classes (Mason 1996; Dular and Tecco-Hvala 2007: 237-246; Križ et al. 2009: 117-121). This argument has been supported by the presence of grave goods including weaponry and items of personal adornment, which become more frequent in the graves of this period (Mason 1996; Križ et al. 2009: 117-121; Črešnar 2010; Mason 2013; Mason and Mlekuž 2016). This is observed most prominently in male graves, which are found to contain a larger array of grave goods in the Iron Age, relative to earlier Urnfield type burials (Mason 1996: 76-80).

The cremation rite itself would have differed significantly from the modern, westernised practices. In Britain, for instance, the cremation process as a means of disposing of bodies is comparatively fast, controlled, risk-free, and perhaps most importantly – out of sight (McKinley 1993; Quinn et al. 2014: 6-12). Through this method, modern-day experiences of the cremation rite can be viewed as relatively efficient and sanitised. Consequently, those who experience the cremation funerary rite today would have a significantly different experience to those witnessing a cremation during the Late Bronze Age or Early Iron Age.

Forensic work has highlighted events that might occur during the open cremation process of a fleshed body (Bohnert et al. 1998; Alunni et al. 2014). For instance, exposure to heat causes the muscles and connective tissues to contract, resulting in the 'pugilistic pose' or 'attitude' (DeHaan 2015: 14). This is observed as the hands balling into fists, legs and arms flexing at the knees and elbows and the chin being pulled in towards the chest via the bending of the neck. As these contractions persist, kinetic energy is released through the contractions of muscles and breaking of bones (Symes et al. 2015: 41-50). This fracturing continues as the organic component of the bone is burned away and the bone dehydrates (Symes et al. 2015: 41-50).

As the temperature of the body rises, the rapid evaporation of liquids results in gas expansion. These gasses are released through the body orifices as jets, but if these exits aren't available, tissues can explode (Bohnert et al. 1998). An example of this would be the "pressurized venting of organic material…" from cranial fractures and forced openings in sutures (Alunni et al. 2014: 169). In addition to this, gas exiting the body, for example through the throat, has been reported to cause the body to release moaning sounds (Williams 2004).

Coverings or wooden containers may have shielded the corpse from the initial heat, but these would have disintegrated probably within the first half an hour of the cremation process, revealing the body (Bohnert et al. 1998). As the process continued, the hair, skin, muscle and organs would have been destroyed within view of witnesses (Bohnert et al. 1998). Forensic observations have additionally indicated that open, wooden pyres are not sufficient for the total destruction of the body. Furthermore, that the required high temperatures and duration would be difficult to maintain without the continual addition of fuel, agitation of the fire, and specific knowledge of pyre technology (Alunni et al. 2014). Without these factors, it has been argued that open-air cremation could not have been maintained beyond 60 to 90 minutes (Alunni et al. 2014). The total removal of soft tissues in a modern cremation setting can take up to several hours (Bohnert et al. 1998). The identification of large quantities of fully calcined, white bone from Kaptol and Kapiteljska njive, subsequently indicates that pyres were maintained throughout the cremation process, with fuel probably added. Conversely, the darker colouration of the bone collected from Ljubljana SAZU could indicate that pyres were less skilfully built or maintained.

In addition to the effects of the fire on the body itself, the pyre would have created a further spectacle. The light and smoke expelled from the fire may have varied based on fuel type and pyre construction, which may have been developed and chosen specifically for the individual to be burnt (Brück 2014: 124-126). For example, ethnographic examples from the Nivkh (north-eastern Siberia), reported by Black (1973: 66-75), demonstrate how wood species may have been chosen for fuel depending on the age of the deceased (Black 1973: 66-75; Williams 2004). For the Nivkh, It was believed that the sounds of the Larchwood cracking would frighten the spirits of children, and therefore this variety of wood was used only for the cremation of adults (Black 1973: 66-75;

Williams 2004). Different species would also have resulted in different smoke quantities and smells (Williams 2004; McKinley 2006).

It is, therefore, argued here that the cremation rite was not only a hypothetically graphic and multi-sensory event but also a potentially intimate affair designed to linger in the memory of those who witnessed it (Williams 2004; Williams 2014; Williams 2015). The drawn-out nature of the process itself provided the opportunity for the identity and personhood of the deceased individual, and that of the mourners, to be played out at various stages (Black 1973: 66-75; Williams 2004). The body may have been laid out while fuel was collected and the pyre constructed (McKinley 2006). Each task may have been carried out by a different family or community member (Black 1973: 66-75).

The finding of burnt metalwork and worked animal bone throughout the analysis of cremated bone from the ENTRANS study area also suggests that the body was dressed for the pyre and that items of personal adornment and probably other objects or materials were burnt alongside the deceased. This would have been another method of displaying various parts of the individuals' identity, drawing parallels with that of inhumed individuals (Williams 2004; McKinley 2006; Brück 2014: 119-139). The identification of fewer grave goods in cremation graves relative to inhumation graves could be the result of the destruction of these objects during the cremation process. The addition of unburned grave goods in association with fragments of burnt objects alludes to the necessity for two sets of objects: pyre goods and grave goods. The number, quality and source of these objects may have been used to express aspects of the deceased's social persona and identity in a similar way to that of inhumation graves (McKinley 1994b; Williams 2005; McKinley 2006; Williams 2015: 263-265).

The burning of the body itself was likely a unique event; differences in body mass, musculature, fat content, age/sex, condition of the body and the use of coverings would have all made the burning of each body slightly different, with the potential of altering the experience of witnesses (Williams 2004; McKinley 2006; May 2011; Symes et al. 2015: 29). Additionally, there was also the risk of the body failing to burn if, for example, weather conditions changed or were poor, the pyre was not built correctly, or for other reasons. The common presence of black and brown bone, particularly from Ljubljana SAZU, suggests that the cremation process was not always fully successful in terms of the total removal of soft tissues, or calcification of the bone.

Following the 'transformation' of the body during the cremation process, bone elements required recovery and sorting. At this point, the living would be expected to work through pyre debris that may have still been hot and was probably dirty, to find the remains for final deposition (Black 1973: 66-75; Williams 2004; McKinley 2006). Bone elements in most scenarios would still have been in broad anatomical position and still in large, recognisable pieces (McKinley 1994a; McKinley 2006; Alunni et al. 2014). Long bones, skull fragments and vertebrae identified from the current study have been found to survive the burning process reasonably well. It is the intentional breaking of the bone during burning, or the handling or raking of the bone afterwards that would be the cause of most fragmentation – especially if the remains had not completely cooled (McKinley 1994a; Alunni et al. 2014). In addition to this, there is a high probability that burnt flesh and soft tissues were still present, adhering to bone fragments (Williams 2004; McKinley 2006). Again, this contact with the transformed remains had the potential for an increased level of intimacy than is usually associated with the inhumation rite.

The final deposition of the burnt remains seems to be under-representative of the whole body in almost every example examined as part of this project. This is reflected in the overall weights of the deposits themselves. McKinley has argued (based on work carried out in modern crematoria) that the remains of a fully cremated adult should weigh in the region of 1.6kg (McKinley 1993). Although it is accepted that archaeological deposits are significantly less than this due to poor recovery, taphonomic damage and loss during excavation and subsequent cleaning (McKinley 1993).

The cremation deposits from Late Bronze Age Slovenia most commonly weigh less than 500g, including animal bone. It is unlikely that post-depositional circumstances are recurrently resulting in the loss of over 1kg of material. It is therefore argued that the remains of the whole individual were not collected for deposition in the first place. This could have been due to a variety of causes. The representation of the bone elements identified from the Slovenian deposits suggests that the largest elements, such as the femora, tibiae, skull and forearms were frequently selected. This suggests that the most accessible and recognisable elements were favoured. The body had been transformed through a drawn out and destructive series of processes, where the remains of the individual were now no longer recognised as being a person (Brück 2006; Brück 2014: 129-131). For this reason, it may not have been important for the total of the skeletal remains to be reclaimed, especially if some parts of the body were still fleshed. Conversely, as the cremation rite itself has been argued here as purposefully creating a vivid memory, perhaps elements of the skeleton were taken by mourners as tokens, or mnemonic devices to be circulated, buried, scattered, or curated elsewhere (McKinley 2006; Brück 2014: 131-137; Williams 2015: 263).

Evidence for the possible selection and/or curation of bone was observed in cremation deposits recovered from the cemetery site at Ljubljana SAZU. Here, there were several instances where fragments of unburnt skeletal remains were placed alongside cremated remains (Graves 106, 158, 289 and 264). Notably, the parietal bones of a sub-adult were found in association with a black and grey-white neck and head of a femur and a cranial fragment of an adult (Grave 264). Other examples were the inclusion of an adult petrous bone, unburnt ribs, an unburnt animal scapula (most likely bovine) and four articulating fish vertebrae (most likely trout). Without more detailed information regarding these graves, it is difficult to assess whether these were intended inclusions, or whether remains have become mixed during post-depositional, taphonomic processes. If, however, these unburned remains could be positively related to cremation graves, then their inclusion would be evidence of the collection of previously skeletonised human and animal remains for internment with another individual.

10.1.3 Cremated animal bone

The presence of burnt animal bone co-mingled with human remains found in many of the cremation graves examined as part of the ENTRANS project may be indicative of two things. Firstly, that feasting took place around the time of the cremation rite. The identification of species such as deer and sheep may support this theory when combined with contextual information, such as the vast quantities of pottery sherds found at the cemetery of Obrežje. Here, the cemetery seems to have been the focus of repeated social gatherings close to the graves (Mason 2009). Secondly, animals were sacrificed and burnt with the body as an offering. The identification of species such as horse and dog, or “companion animals” is more indicative of this interpretation (Bond 1996; Bond and Worley 2006). The quantities of cremated animal bone found associated with the Early Iron Age cremation burials from Kaptol, frequently of horse remains and large mammals, also support this hypothesis.

Overall, it is argued here that the practice of the cremation rite had the potential to be more intimate and engaging than has been previously thought. The drawn-out nature of the process of the cremation rite allowed for numerous opportunities to recognise, portray and celebrate the identity and persona of the deceased. The burning of metal items and animal remains, whether they were whole animals or joints of meat, involved a similar practice of conspicuous consumption seen in inhumation, only the objects themselves were destroyed in view of those who were there.

The burning of a body had the potential to be violent, dramatic, and memorable. Williams (2004; 2008: 274) argues that the body itself possessed agency, and consequently had the ability to affect the experiences and the memories of those that witnessed it, arguably more so during the cremation ritual than during an inhumation burial, because of the visibly transformative nature of the practice. It is important, therefore, to recognise the personal and experiential aspects of the cremation rite as a succession of different processes, and to consider more than just the final deposit of bones (Williams 2004). To do this, the study of burnt human remains is still vital to our comprehension of changing attitudes and approaches to the dead during the Late Bronze Age/Early Iron Age transition in Slovenia and north-east Croatia. Deposits of cremated remains continue to be an untapped resource, which needs to be accessed more regularly to further our understanding of identity, cosmology, and social structure in prehistory.

10.2 The inhumation rite

The adoption of the Inhumation rite has been viewed as an evolution of social structure and practices, rather than an influx of new people (Frie 2012). This is evidenced by the identification of cremation and later inhumation burials within the same tumuli, such as at Metlika/Hrib, as well as the reuse and referencing of previous settlement and funerary sites (Mason 2009; Frie 2012; Mason and Mlekuž 2016). However, following the current study (particularly using radiocarbon dating), it has become clear that during the Late Bronze Age individuals were not always restricted to Urnfield type cremation burial. Some exceptions have been analysed as part of this research from the cemetery site of Obrežje, Slovenia. Here, unburnt individuals were buried in supine positions within an urnfield cemetery. Two males, one female and two children were identified. For the most part, grave goods are rare for these individuals, though the two males were buried with bronze dress pins. The Late Bronze Age female grave also included a ceramic cup containing a small quantity of human (possibly curated) remains, that were found to represent at least one adult and one young child or infant. One of the adult males (2544) was radiocarbon dated to the Iron Age. However, this is still unusual, as it would seem they were purposefully inserted into a Bronze Age Urnfield, a decision that was not frequently repeated. This cemetery, therefore, can be argued as displaying a connection between individuals and memory of past practices and people, both communities and specific persons.

Moving into the Early Iron Age, the changes seen in the approaches to death and funerary activity between the Bronze Age and Early Iron Age was probably linked to shifts in social structure and local perceptions of cosmology and how the world functioned (Mason 2009; Oestigaard 2013). This can be observed in a number of factors including, funerary rite, cemetery location and construction, as well as objects associated with graves. These changes were probably influenced by shifting circumstances across the region, with increasing access and control over communication and exchange networks, resulting in amplified competition between communities (Mason 1996: 75-80; Potrebica and Dizdar 2004; Šimek 2004: 81). A key example would be that fortified settlement sites in the Iron Age were developed in upland locations, as opposed to the previously unfortified upland and lowland sites during the Bronze Age (Mason and Mlekuž 2016). These later, Iron Age upland sites consisted of hillforts, such as Vinji vhr.

Around the same time, the large, flat urnfield cemeteries were no longer created and the introduction of burial under tumuli was introduced.

The positioning of Early Iron Age tumuli has been argued to be significant (Mason 1996: 76-79; Mason and Mlekuž 2016). This has been discussed for the monumental and funerary landscape surrounding the Vinji vhr hillfort. Mason (2016) has argued that the construction of tumuli along route ways leading up to the entrance of the hillfort was a method of controlling movement through the landscape. This differs from the previous Urnfields, which were areas with a high density of graves, thought to have focussed on community-based activities such as feasting and gathering (Mason 2009; Mason and Mlekuž 2016). This has been evidenced at the cemetery of Obrežje, where vast quantities of pottery have been uncovered around the borders of the cemetery (Mason 2009). Furthermore, the links between urnfield cemeteries or cremation platforms, with natural (especially wet) landscapes has been argued (Mason 2009; Mason and Mlekuž 2016). This differs from the locations of later Iron Age tumuli, which are more frequently associated with man-made structures, such as roadways and settlements (Mason and Mlekuž 2016).

Even where the cremation rite was retained as the primary method of body disposal in the Iron Age, these activities seem to have been significantly elaborated, relative to the Late Bronze Age (Šimek 2004: 85-127; Potrebica and Mokos 2016: 39-65). This is most visible at the site of Kaptol, where monumental tumuli were constructed for single burial events (Potrebica and Mokos 2016: 39-65). Furthermore, the assemblages of cremated remains, especially Tumulus 6, have evidenced the mass cremation of at least one human and numerous animals (See Chapter 5). This would likely have required large and/or multiple pyres and therefore an example of significant conspicuous consumption (Bond 1996; Potrebica and Mokos 2016: 39-65).

Even though the format of the funerary rite is observed to alter significantly, the analysis of human remains has shown that Urnfield cemeteries and later Iron Age tumuli/cemeteries contained both adults and non-adults. Issues with the sex assessment of cremated remains have led to difficulties investigating relative numbers of males and females included within Urnfield cemeteries. The osteological analysis of inhumation graves, however, has suggested that Iron Age inhumation burial was accessible by both sexes in relatively similar numbers. Furthermore, previous interpretations of these tumuli as family or kinship burial places have been supported by the identification of three siblings via aDNA analysis, buried at Dolge njive.

In terms of the relationships between personhood, identity and objects, no evidence has been found to contradict previous interpretations. Individuals attributed a sex via osteological analysis were largely associated with the expected grave goods (see Chapter 1).

Due to the scarcity and preservation of skeletal remains recovered from the cemetery sites making up this current investigation, it is difficult to form a picture of a representative cemetery population. However, the results of osteological analysis of both inhumation and cremation grave deposits have provided information regarding the homogeneity and heterogeneity of funerary practices throughout the Late Bronze Age/Early Iron Age transition, across the ENTRANS study area. Following the osteological analysis, it is apparent that males, females, and children of different ages had access to the inhumation burial or cremation rites across both these time periods. It is posited, then, that access to funerary practices was not constrained solely by age or sex during these periods, within this study area.

The funerary practices of the Late Bronze Age, though strictly coded, have been argued to vary between communities in terms of objects deposited with skeletal remains (Teržan 1999; Črešnar 2010; Črešnar and Thomas 2013). This has similarly been evidenced by the variation in the colour, weight and fragment size of cremated remains observed between urnfield assemblages. This supports previous interpretations that have argued for regional approaches to the Urnfield funerary rite based on the presence of different objects and typologies (Mason 1996; Teržan 1999; Črešnar 2010; Črešnar and Thomas 2013). The identification of inhumation graves and curated, unburnt human remains dating to the Middle and Late Bronze Age has also provided evidence for the various approaches to the treatment of the dead.

The sudden movement away from Urnfield type burials to that of graves under tumuli in the Early Iron Age is an obvious departure from previous ideas regarding the proper treatment of the dead. However, the reuse of previous settlement and funerary landscapes, such as the Dolge njive tumuli constructed on top of previous cremation platforms, the founding of the Metlika/ Hrib tumuli on earlier cremation graves, or the continual use of Urnfield cemeteries, such as at Kapiteljska njiva, attests to the importance of the past and perhaps the remembrance of specific individuals and/or communities (Mason 2009; Mason and Mlekuž 2016). Furthermore, although the Early Iron Age graves themselves were relatively elaborate in comparison to the earlier Urnfield type burials, once sealed, these graves became part of a communal monument. Within a mound containing several individuals or more, no one grave would have been outwardly identifiable without prior knowledge of its location (Frie 2012). This knowledge of who was buried within each mound would have been restricted to those who witnessed the funeral, the community, and those who had been informed (Frie 2012). To outsiders, the identity of those buried within the mound may have been unknown. This would also probably have been the case for the previous urnfield graves, some of which may have been identifiable by a small mound or a ring of stones. The differences in the treatment of the dead observed between the Late Bronze Age and Early Iron Age across the ENTRANS study area, therefore, exhibits both homogeneity and heterogeneity. The continuous evolution and adoption of new funerary practices by these people probably relate to an evolving social environment, where the living used the dead to organise their geographical and social landscape and to control how people moved through it.

Chapter 10 Part 2: Life and the Body

Osteological and isotopic analyses can detail more than just how dead bodies were treated after death or how funerary rites were carried out. The investigation of human remains can provide vital information for how communities lived their day to day lives in the past. Osteological examination of skeletons can indicate the prevalence of chronic disease and trauma, while stable isotope ratios can evidence not only the diet of those living in prehistory, but also their metabolic status, hint at agricultural practices and suggest mobility patterns. This information can be related to a time, sometimes significantly, prior to the death of an individual.

This thesis has presented the results of several osteological and isotopic analyses. These methods have been utilised to investigate and discuss multi-scalar patterns, from the population and regional data to individual biographies and life-courses. This chapter will pull together strands of evidence from these separate data sets in a bid to seek out how communities and individuals inhabiting Mid-Late Bronze Age and Early Iron Age Slovenia and Croatia might have lived. This shall be done through the discussion of the overarching themes of population homogeneity and heterogeneity, approached via the sub-themes of diet, health, and mobility.

10.3 Health

As has been previously presented in Section 4.4, the identification of palaeopathological lesions was rare throughout the examination of skeletal remains from the ENTRANS study area. However, the prevalence or absence of palaeopathological lesions is not necessarily reflective of the health status of a population. As has been discussed and argued elsewhere (Wood et al. 1992; van Schaik et al. 2014), the presence of pathological lesions evidencing chronic disease within a population could be counterintuitive. The identification of these lesions would suggest that members of this population were of a sufficient health status to fight infection and disease for extended periods, subsequently allowing sufficient time for pathological lesions to develop (Wood et al. 1992; van Schaik et al. 2014). Conversely, skeletal remains with no evidence of pathological lesions similarly cannot be classed as ‘healthy’ by the simple fact that the person is deceased (Wood et al. 1992). As DeWitte and Wood (2008) note: *“The dying, on average, are less healthy than the rest of the living”* (DeWitte and Wood 2008: 1436). Their health status may have been such that they were unable to fight off disease or infection and consequently succumbed to their ailments before a trace could be left in their bones (Wood et al. 1992; van Schaik et al. 2014). Alternatively, they may have suffered injury or disease related to the soft tissues of the body and therefore also invisible following skeletonisation (van Schaik et al. 2014).

As was also expressed in Chapter 4, the preservation of these remains was such that it is very likely that evidence of palaeopathological lesions had been destroyed. This was compounded by the fact many individuals included in this investigation were cremated. Consequently, it is very difficult to comment on the prevalence of disease in Late Bronze Age and Iron Age communities from this sample.

Another method to assess the health of these populations would be to explore mortality rates of these cemeteries by, for example, comparing the percentages of non-adults, young, middle and mature adults. In the event of a catastrophic episode, such as a natural disaster or the Black Death, mortality rates are altered, reflecting their less discriminative nature (DeWitte and Wood 2008). In a healthy, non-epidemic population, it has been estimated that mortality rates of should follow a pattern of peaks during infancy and old age, and troughs during middle to late childhood and young adulthood (Margerison and Knüsel 2002).

For the most part, it can be argued that the mortality rates stated above are broadly reflected in the overall ENTRANS dataset. However, as has also been discussed throughout this thesis, this sample of individuals has been heavily biased by taphonomic, methodological and cultural factors. It is therefore difficult to detail further the health status of these populations without going beyond the remit of the current project. For example, it could be argued that a relatively high number of young adults were observed, especially at Dolge njive, which could hint at possible health issues, as these individuals should have been more resilient to disease. However, when the taphonomic issues are also considered, it is probably the case that this demography has been biased by the preferential destruction of more vulnerable remains, such as non-adult (increased non-ossified, cartilaginous tissues) and mature adults (reduced bone density), especially females (Walker et al. 1988; Walker 1995; Bello et al. 2006).

Nevertheless, as a key aim of this research is to investigate the advantages of multi-disciplinary and multi-scalar approaches to research questions, a case study focussed upon the health and life of a single individual has been presented in Chapter 7. This biography of an infant, who suffered from chronic conditions throughout most, if not all their life, has provided an example of this form of investigative approach.

10.4 Diet

10.4.1 The influence and importance of scale and resolution

Throughout this thesis, but particularly in terms of the stable isotope analysis, the exploration of data at different resolutions and scales (i.e. regional, inter and intrasite, and even inter and intra-individual scales) has been vital for the interpretation of results. To engage with the themes of heterogeneity and homogeneity of communities inhabiting the ENTRANS study area in prehistory, they have been divided once again at these scales, drawing upon the various threads of evidence produced throughout this work.

A major part of this research was the carbon and nitrogen isotope analysis of bulk collagen extracted from multiple skeletal elements (rib, long bone and dentine) of a single individual. The results of this investigation have provided evidence for the widespread consumption of terrestrial, herbivorous protein (meat or secondary products such as dairy and eggs) in conjunction with a mix of C3 and C4 based plant protein.

The ENTRANS dataset has shown that C4 plants made up a significant proportion of the diet, across all the populations studied, revealing a surprising level of spatial and temporal homogeneity. From this, it can be interpreted that millet was consumed on a large scale across the study area. Furthermore, its prevalence indicates that this crop was not used as either a status symbol or as a famine food. Across Slovenia and inland, northern Croatia, it appears that millet constituted a significant staple crop, potentially from the Middle Bronze Age.

The picture of diet reflected in the human carbon and nitrogen isotope data suggests that communities inhabiting this landscape shared a similar diet, centred on millet and terrestrial animal resources. However, when other isotopic methods are utilised (incremental dentine, enamel carbonate and oxygen isotope analysis) and the diet of animals is explored, it becomes apparent that there are subtle differences that are obscured in this dataset.

10.4.2 Animal baseline

A possible variation in husbandry and subsistence strategies may be identifiable in the carbon and nitrogen isotope animal baseline. Although this baseline has been constructed from a small number of remains, consisting of few species, these isotope results have offered some interesting glimpses into to husbandry practices and livestock management in later prehistoric Slovenia. $\delta^{13}C_{coll}$ values from pigs, sheep/goats and humans have evidenced the prolific consumption of C4 plants (millet) across Iron Age Slovenia (Nicholls and Koon 2016). This indicates that millet was used as a shared protein source for humans and animals, but whether this demonstrates the direct consumption of millet as animal fodder is more difficult to discern.

The management of pigs may have been geographically diverse. The wide range of isotope ratios has suggested that, as non-specialist feeders, pig diet may have had a variety of sources. Some pigs (CRT, gorenja vas and Novo mesto) have provided $\delta^{13}C$ and $\delta^{15}N$ values very similar to that of humans, which may be reflecting the ingestion of human crop or food waste. Other pigs (Zagorje ob Savi) have provided isotope ratios akin to that of other herbivores, primarily cattle, from the rest of the dataset. This heterogeneity could be the result of a different approach to animal management. The $\delta^{15}N$ values (0.7 and 0.3‰) exhibited by the piglet remains recovered from Ljubljana Congress Square remain unexplained and additionally suggest a unique dietary or metabolic influence within this dataset.

The distinction in both $\delta^{13}C$ and $\delta^{15}N$ values between wild and domestic animals suggests dietary intervention by humans in this latter category. This can be viewed as being directly or indirectly caused by foddering, penning or controlled grazing, as evidenced by the cattle and sheep/goat remains (Bogaard 2004; Bogaard 2005; Tafuri et al. 2009; Fraser et al. 2011; Madgwick et al. 2012). Moreover, this also potentially indicates that there was a close relationship between crop and animal husbandry practices.

Nitrogen isotope ratios from domesticated species appear to be elevated in comparison to isotope ratios from wild animals (deer), which suggests that domesticated animals may have been consuming food produced on nitrogen enriched, cultivated soils (Bogaard 2004; Bogaard 2005; Halstead 2006: 44-46).

High $\delta^{13}C$ values seen in cattle, sheep/goat and pig remains are evidence for the consumption of C4 plants, probably millet.

Human isotope ratios have shown that millet was an important food source for whole communities and that it was not produced solely as a means of maintaining livestock. The lack of evidence for the foddering of animals on millet other than at Ljubljana Congress Square does, however, suggest that it is less likely that humans were routing a C4 signal indirectly through the consumption of meat or secondary animal products. This additionally strengthens the argument that millet was an important cereal crop for direct human consumption.

Other investigators have argued for the mutually beneficial co-management of livestock and crops, whereby domesticated animals are kept healthy by grazing on arable land, while simultaneously providing manure and helping to sustain soil structure and condition (Bogaard 2004; Bogaard 2005; Halstead 2006: 44-46). This hypothesis could account for the variable $\delta^{13}C$ and $\delta^{15}N$ values seen from animals from this investigation.

10.4.3 Humans: bulk collagen carbon and nitrogen stable isotope analysis

From the bulk collagen isotope analysis, there does not appear to be any obvious distinctions between social groups based on protein intake at the regional scale. All age groups and both sexes exhibited generally similar ranges of carbon and nitrogen isotope ratios. One exception to this was Infant 1 from Zajorje ob Savi (see Chapter 7), where health and illness were more likely the main cause of variability.

<u>Inter and intra-individual scale analysis of bulk collagen carbon and nitrogen isotope analysis</u>

When the stable isotope data was examined at the individual and inter-individual scales, the effects of dietary variation and metabolic influences over this data became more apparent. This was primarily observed within the non-adult dataset, as dental tissues were sampled. As these tissues do not regenerate or remodel, these tissues provide a snap-shot into childhood diet and health.

When exploring the bulk collagen carbon and nitrogen isotope data, the prevalence of comparable isotope ratios from different skeletal elements, representing different life stages, has indicated that diet remained relatively consistent throughout life. When individual life courses were explored comparing the dentine, rib and long bones from a single person, however, some small variation was observed. In almost all instances, this was identified as a decrease in $\delta^{13}C$ values between dentine samples and associated rib and long bone samples. However, for the most part, this variation was negligible and could be reflecting differences in bone turnover rates, rather than dietary variability.

When all the bulk collagen samples were examined together in Section 6.2, it was noted that apex dentine samples were more variable in their isotope ratios than either rib or long bone collagen samples. Within the long bone and rib categories, abrupt changes or seasonal fluctuations in isotopic ratios were probably being masked by the averaging effects of bone turnover (Hedges et al. 2007; Beaumont et al. 2015). Conversely, dentine samples were recording a higher resolution of isotopic change as the tissue is actively forming and does not regenerate (Beaumont et al. 2015). Therefore, any alterations in the isotopic composition of diet caused by, for example, seasonally specific crop use, is more likely to have a noticeable influence on dentine samples. This is a probable cause for the increased variation observed in the apex dentine data relative to the other two tissue categories. This variation was observed more clearly in the $\delta^{13}C$ values obtained from incremental dentine analysis, where this range of values is seen to broaden further because of the higher resolution of this sampling method.

10.4.4 Incremental dentine carbon and nitrogen isotope analysis

When compared to the bulk collagen isotope data obtained from bone, the use of incremental dentine analysis for carbon and nitrogen isotopes has revealed a more variable situation. High-resolution methods have shown childhood diet to be surprisingly complex. For example, there is evidence from the incremental dentine to indicate a constant change in the relative importance of C3 and C4 plants. Furthermore, fluctuating $\delta^{15}N$ values throughout the isotope profiles of permanent and deciduous teeth have evidenced changing protein sources. Overall, it was difficult to pinpoint any specific cause for the variation in both $\delta^{15}N$ and $\delta^{13}C$ values during childhood. There is a high probability that a mix of dietary change and metabolic processes played a part in the isotopic variations reflected through their dentine increments. Co-varying fluctuations in both carbon and nitrogen isotope ratios were common in most isotopic profiles from incremental dentine analysis. Prior to weaning, any changes to the isotopic composition of the mother's diet would also be recorded in the actively forming tissues of the infant (Beaumont et al. 2013b; Beaumont et al. 2015). As seen in the isotopic profiles generated from permanent teeth, which include increments most likely formed post-weaning, $\delta^{15}N$ and $\delta^{13}C$ values continue to vary throughout the development of the teeth. Similar dietary variability could have occurred in adult diet, however, due to the slower rates of bone turnover for rib and long bone, the bulk sampling of bone collagen would have masked these isotopic variations.

10.4.5 Carbonate carbon and oxygen isotope analysis from tooth enamel

When these same individuals were revisited through the sampling of their tooth enamel for carbonate carbon analysis, some more subtle distinctions were observed. These were primarily visible from the Križna gora sample, probably because of the larger size of the dataset.

It was noted that, although the overall combination of foodstuffs was probably the same throughout the cemetery group, the composition in terms of quantity of each food type, may have differed. Two clusters of data were identified after being modelled. Of these two groups, it was noted that one was primarily made up of females (either biological or typological). Following the model set out by Froehle et al. (2010), this cluster of individuals was consuming a whole diet (during enamel formation) with a higher proportion of C4 based non-proteins than the rest of the group. This suggests that this second group were ingesting a higher quantity of millet during childhood.

It is difficult to ascertain whether this isotopic variation is really reflecting a sex-based difference in dietary composition, which would have been noticeable at the time of consumption, or if this distinction is the result of personal taste or communal availability at the time of enamel formation (e.g. seasonal). A larger data sample could enhance or obscure this apparent difference. However, in comparison to the bulk collagen isotope ratios, this carbonate carbon data, when modelled, is evidence for potential heterogeneity within a cemetery group in terms of dietary composition (relative quantities), based on the same general food items.

The results of oxygen isotope analysis provided another set of data related to inter/intra-individual dietary heterogeneity and homogeneity. This was observed in the comparison of deciduous and permanent teeth. Here, an offset in $\delta^{18}O_{carb}$ values of 1.2‰ on average was identified between the two tooth types from the same individual. Combined with the carbonate carbon results, which exhibited a shift from lower to higher $\delta^{13}C_{carb}$ values between the same deciduous and permanent teeth, it was possible to make interpretations regarding variability in childhood diet. As previously explained in Sections 6.5.4 and 8.7, these shifts in isotope ratios are most likely related to the onset of weaning. This was interpreted in the oxygen isotope ratios as a change in the relative importance of water sources, i.e. a reduction of breastmilk and increase in local drinking water consumption (Wright and Schwarcz 1998; Wright and Schwarcz 1999; Britton et al. 2015). In the carbonate carbon isotope ratios, the movement from lower to higher $\delta^{13}C_{carb}$ values was observed as evidence for the introduction of solid foods, which would have altered an infant’s diet from one of high lipid content to one inclusive of a high proportion of carbohydrates (Wright and Schwarcz 1998; Wright and Schwarcz 1999). As the carbonate fraction of the tooth enamel is more heavily influenced by carbohydrates than lipids, this shift in isotope ratios is subsequently tracking a change in the composition of these infant’s diets (Wright and Schwarcz 1998; Wright and Schwarcz 1999; Britton et al. 2015). From this combined data, it was possible to estimate the onset of weaning occurring prior to the age of 3.5 (the age at which the crown of the permanent first molar is complete) years of age, and probably earlier.

When the incremental dentine data is also considered together with enamel data, $\delta^{15}N$ and $\delta^{13}C$ values are seen to change rapidly within the first increments of both the deciduous and permanent teeth. This could be evidence for the onset of weaning within the first year after birth, with the fall in $\delta^{15}N$ values identified as a drop in trophic level and $\delta^{13}C$ values altering relative to the introduction of a new carbon source (Millard 2000; Fuller et al. 2006; Jay et al. 2008; Beaumont et al. 2015). The elongated trend of falling $\delta^{15}N$ values over what was probably years of tooth root development could also be evidence for the practice of combined feeding, with breast milk continuing to play a role in childhood diet after solid foods had been introduced (Reynard and Tuross 2015).

The sampling of non-adult remains who did not survive childhood has inherent issues regarding representativeness and the relationships with morbidity. It is difficult to argue whether this is a true representation of childhood diet, or whether these dietary practices in some way influenced their deaths (Wood et al. 1992; Beaumont et al. 2013a). Nevertheless, the selection of non-adults sampled for this comparison of deciduous and permanent teeth covered a wide temporal and spatial area.

10.5 Social implications of Diet

From the interpretations made of the isotopic data, as detailed above and in Chapters 6, it is possible to create some hypotheses regarding the social and cultural inferences of this dietary evidence. The following discussion addresses the implications of dietary homogeneity/heterogeneity and the relative importance of millet in European prehistory.

10.5.2 Millet in prehistory

The stable carbon isotope data set indicates that individuals inhabiting central/eastern Slovenia and north-eastern Croatia were ingesting a high quantity of C4 plants. $\delta^{13}C$ values still evidence the consumption of C3 plants (probably emmer or spelt-wheat, barley and other pulses and vegetables), which is supported by the archaeobotanical evidence (Dular and Tecco-Hvala 2007: 208-209). However, for many of these individuals, millet played a major role (indicated by $\delta^{13}C$ values as high as -12‰) in their diets, suggesting that it was likely a dominant crop. This contradicts many of the studies that have previously implied that millet usually played a minor role in agriculture and diet during prehistory (See Section 1.4.1) (Killgrove and Tykot 2013; Moreno-Larrazabal et al. 2015; Murphy 2016; Reed and Drnić 2016). It is very probable that this dataset reflects the widespread cultivation and consumption of millet in this area. Furthermore, the dataset (combining different life-stages through the examination of dentine, rib and Long bone collagen samples) suggests that this cereal was a key staple for all members of society (men, women and children), rather than a famine relief food or supplement. Moreover, this appears to have been the case from at least the Middle Bronze Age at the sites of Obrežje and Sv Petar Ludbreški, and even into the present day, where millet is still commonly eaten within the study area (P. Mason pers comm. 2015). Millet within the study area was therefore not exceptional, but rather the norm for these communities.

At the time of its adoption, millet may have been viewed as "*exotica*", through which ties and networks with the north and east of Europe and Eurasia could be displayed (Valamoti 2016). The arrival of millet into ancient Greece has been associated with the arrival of the horse towards the end of the 3rd millennium BC (Valamoti 2016). Additionally, the importation and adoption of this cereal has been linked with the nomadic cultures inhabiting the Eurasian steppes and further into Mongolia (Liu et al. 2012; Moreno-Larrazabal et al. 2015; Knipper et al. 2016; Valamoti 2016). The consumption of this grain on a large scale, therefore, could have been a way of displaying network relations or status. However, as Lightfoot et al. (2013) argue in their review of isotopic evidence for millet consumption across Eurasia, millet was no longer "exotic" or "novel" in Europe by the first millennia BC. This interpretation is therefore flawed.

In their review of isotope data from 374 sites from across Eurasia (301 excluding sites in China), Lightfoot et al. (2013) could identify only eighteen populations where individuals ate millet in the first millennium BC, located in the Czech Republic, Greece, Italy, Ukraine, Austria, Croatia and Slovenia. Only seven of these sites provided evidence for most of the population having eaten millet. The carbon isotope ranges of some of these studies are shown in Figure10.8. Subsequently, it was argued that the consumption of millet as a staple in Europe was the exception, rather than the rule. Furthermore, it was argued that, where it was available, the archaeological evidence (grave goods, weapons, horse burials etc.) indicated that “millet eaters” were probably of a higher status (Lightfoot et al. 2013). This has similarly been identified in this current study, where individuals have been sampled for stable isotope analysis from cemeteries associated with grave goods indicative of a higher social status (glass and amber beads, situla art, weaponry, metalwork) The cemeteries themselves have also been argued to contain individuals connected with prominent hillfort settlements (for example Vinji vhr) and production centres for high-status glass beads and metal working (Križ et al. 2009: 101-107; Mason 2013). The interpretations for the use of millet as a supplement/famine/low socio-economic food, or as a fodder crop, therefore, also do not work in this instance.

The high-level consumption of millet within this study area subsequently remains open to interpretation. Nevertheless, when compared to contemporaneous stable isotope data from across Europe, this collection of individuals appears exceptional in terms of their diet. The cereal itself may not have been used as a symbol of status within communities, but perhaps this crop can be viewed as a link between local populations, sharing to some extent a kind of common identity, but simultaneously separating them from other populations in Europe, which have been shown to subsist on a C3 based diet.

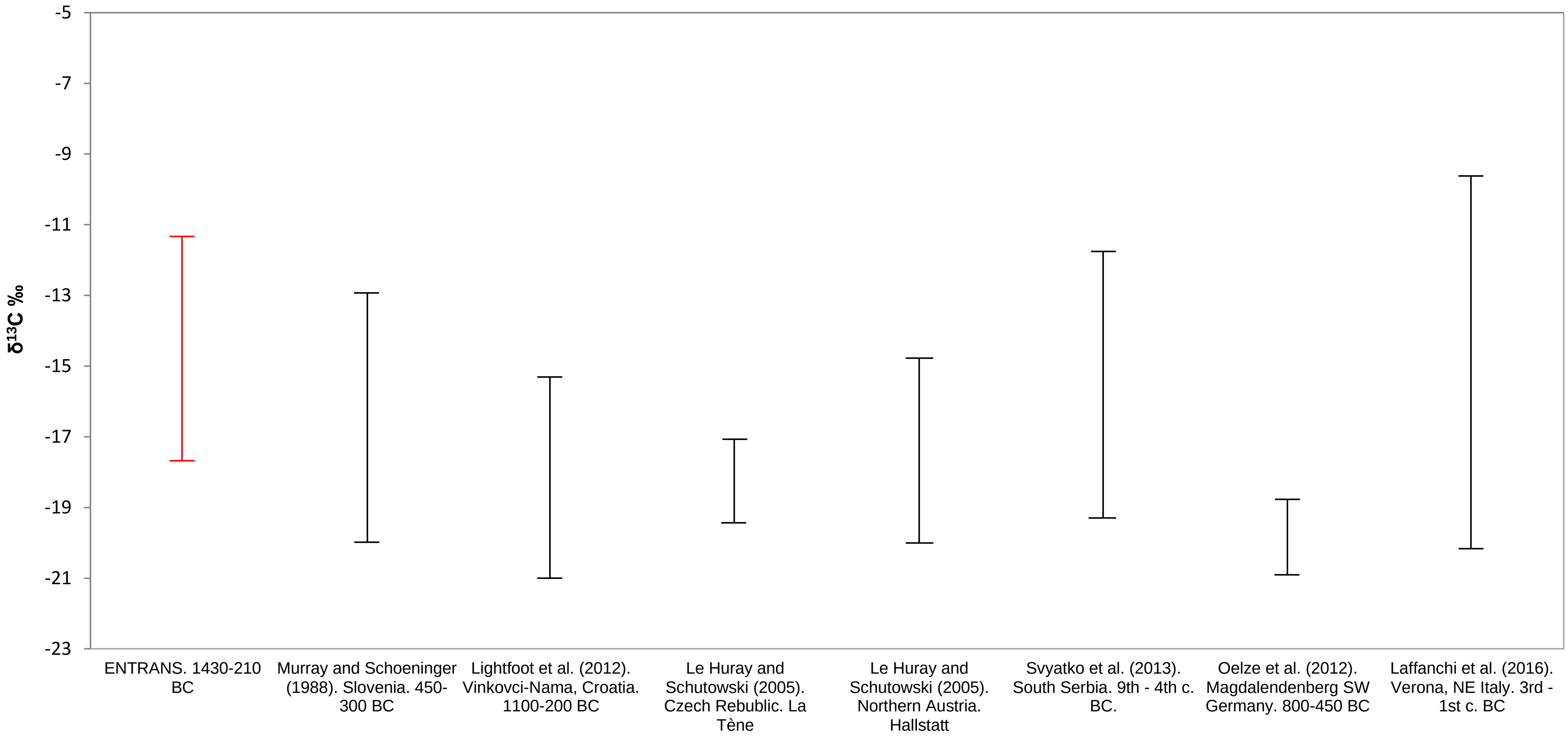

Figure 10.1 Ranges of carbon isotope ratios taken from previous investigations on palaeodiet in Iron Age Europe. For most of these studies, millet consumption has also been identified (Except for Oelze et al. (2012). However, millet eaters from the Czech Republic and Northern Austria made up less than half of their data sets. These ranges are compared with the ENTRANS carbon isotope bulk collagen dataset (rib, dentine and long-bone)

10.5.2 Diet versus Food

The high level of isotopic homogeneity found across all the individuals in the ENTRANS dataset displayed in the bulk collagen carbon and nitrogen isotope ratios is interesting. Most of the data from this analysis clustered tightly, indicating a mix of C3 and C4 plants and additional herbivorous animal protein. This consistency in stable isotope ratios indicates that social status and cultural identity was not necessarily negotiated or displayed through access or restriction to specific (isotopically distinguishable) food types. This would, therefore, have had to have been conveyed in other ways.

It is important to remember that ‘diet’ is also a social construct, which can be dictated and regulated through, for example, a variation in quality, quantity or animal joint type (Twiss 2012). Furthermore, levels of engagement relating to the acquisition, preservation, storage and cooking of food may have been significant for reflecting positions held within a social structure or hierarchy. (Twiss 2012; Hastorf 2016: 1-16). Isotopically, these foods may be indistinguishable, but in practice, they may have held important roles and symbolism, which could have highlighted different members of society, times of year and cultural performances (Halstead 2012: 21-51; Hastorf 2016: 1-16)

Social etiquette may have played a key role in the construction, performance and maintenance of these social hierarchies and relationships. At a feast or within the household, factors such as differential food (quality, quantity, source, ingredients), seating, tableware, timing/ control/ carrying out of service and behavioural expectations may have been used to express social, economic or political status, age or gender (Twiss 2012).

Foodstuffs produced for more formal occasions may have been differentiated through increased manual labour that went into their production. For example, foods deemed to have a higher value may have included bread made with finer flour, decorated loaves, and fresh meat (Halstead 2012: 21-51). Cereals also used to produce lower status items could have been refined by removing higher quantities of bran or seed coatings, resulting in a product perceived to be of a higher quality (Halstead 2012: 21-51). Furthermore, that the consumption of these more refined foods on a regular basis, involving higher levels of manual labour and wastage, may have been restricted to those with relatively high wealth or influence (Halstead 2012: 21-51).

Although status could have been displayed through the varieties of food available to various individuals, such as exotic ingredients, it may also have been symbolised by an individual's or household's ability to gather and maintain a surplus food supply (Halstead 2012: 21-51; Bogaard et al. 2015). Through this surplus, these households would have been able to qualify themselves for inclusion in social networks via hosting and food exchange (Arnold 1999; Harding 2000: 401). Access to these networks could lead to social manoeuvrability through the attending and hosting of feasts and ceremonies, encouraging the forging and maintenance of social bonds and alliances, via the creation of obligations and the paying of debts (Arnold 1999; Dietler 1999; Twiss 2012).

Maintaining a food surplus secured a household against poor harvests, but also ensured that labourers could be mobilised to safeguard the continuation of this surplus (Halstead 2012: 21-51; Styring et al. 2017). For example, Halstead (2012) commented on how farm labourers in historic Greece were more likely to take work with landowners who fed them well. This also meant that the landowner could choose the best or most experienced workers, which would act as further security. Economies whereby food was a means of paying wages, taxes and tributes should, therefore, also be considered when exploring the interplay between food and social structure (Pollock 2012; Twiss 2012). Again, this would not necessarily have had to have been related to food type, but potentially defined by quantity, quality, origins and status of the product. In this situation, the interaction between the donor and the collector is probably more reflective of social hierarchies and distinctions (Pollock 2012; Twiss 2012).

The difference in status seen through an individual's interaction with food would probably have been related to actions and processes with which they were involved. For example, whether they were involved in raising/growing, processing, preparing, cooking, eating or discarding of food (Twiss 2012). The context of these activities may also have played a crucial part in the display of an individual's role within society. For example, a cook within the household may have been allocated a relatively low status, whereas an individual preparing and cooking food for an elite could have been recognised as a skilled craftsperson or artisan (Twiss 2012).

Grave goods, including sets of ceramics (e.g. cups, serving vessels, bowls etc.), uncovered at the cemeteries included as part of the ENTRANS project indicate that feasting was a major element of society (Mason 1996; Potrebica and Mokos 2016: 47-50). This can also be observed in the quantity of pottery found, for example, at Obrežje, which indicates the revisiting of the cemetery as a succession of communal gatherings (Mason 2009). Depictions of feasting, gathering and communal consumption have also been identified in the local situla art (Križ et al. 2009: 131-135; Frey 2011; Büster et al. 2016). This combined evidence suggests that the communities inhabiting this landscape were engaged in these social, political and economic practices via the structuring and manipulation of food and cuisine.

It is, therefore, important that other methods are also considered when attempting to reconstruct diet in the past. For example, the collection and identification of faunal and floral remains, but also more analytical techniques such as lipid residue analysis of ceramics. The comparison of this latter method with ceramic typologies can yield vital information for the cooking, preparation, storage and presentation methods used in past societies (Evershed et al. 1992; Evershed et al. 2001; Craig and Collins 2002; Evershed 2008). This methodology is being carried out elsewhere as part of the ENTRANS project (PhD Researcher, Beatriz Bastos), and will hopefully elucidate more fully the paleodiet of communities inhabiting the East Alpine region during the Late Bronze Age/Early Iron Age transition.

10.6 Mobility: oxygen and strontium isotope analysis

10.6.1 Oxygen isotope analysis

The archaeological evidence suggests that this area of temperate Europe was an important crossroads and played a role in significant, prehistoric long-distance trade and social networks (Šimek 2004: 94-95; Potrebica 2008; Potrebica and Dizdar 2014; Potrebica 2016: 109-122; Potrebica and Mokos 2016: 39-65). It is likely that people were moving between different locations and centres. The presence of previously identified, exotic grave goods evidences this, such as Greco-Illyrian (Novo mesto) and Corinthian helmets (Kaptol), and amber from the Baltic coast (Križ et al. 2009: 137-139; Potrebica and Mokos 2016: 52).

Based on the analysis of strontium and oxygen isotope ratios from this research, very little evidence to support an argument for long distance, residential mobility was observed. Two individuals (Graves 22 and 32) from the cemetery at Križna gora were identified as potential outliers following oxygen isotope analysis (see Section 8.5.1). However, following strontium isotope analysis of seven individuals from the same cemetery, including Grave 32, no supporting evidence for immigration was observed.

When the contextual information for these two graves is additionally investigated, their style and contents similarly give no further evidence that these two individuals were non-locals. Grave 22 (Figure 10.9) contained two vessels and fibulae, while Grave 32 (Figure 10.10) contained a vessel and a dress pin. None of these grave goods is unusual to this cemetery.

As has already been discussed in Chapter 8, the potential range of oxygen isotope ratios from local drinking water can vary widely. The unusual values obtained from these two skeletons could be the result of natural variation. Alternatively, human activity including brewing, boiling and strewing has been shown to significantly alter the $\delta^{18}O$ values of water (Brettell et al. 2012), but this would have led to the increase of $\delta^{18}O_{carb}$ values, and these two individuals had the lowest $\delta^{18}O_{carb}$ values of the data set. If all members of the community were consuming a similar diet, which the carbon and nitrogen isotope data would suggest, then the effects to this human activity should have influenced the $\delta^{18}O_{carb}$ values of all the individuals included in this study, in a similar manner. At present, the use of this method, therefore cannot discount the possibility of residential mobility through regions with similar climates. As was also discussed in Sections 8.2 and 8.7, the average oxygen isotope ratios throughout temperate Europe are reasonably similar. This is because of the lack of significant climatic variation (Garvie-Lok 2009).

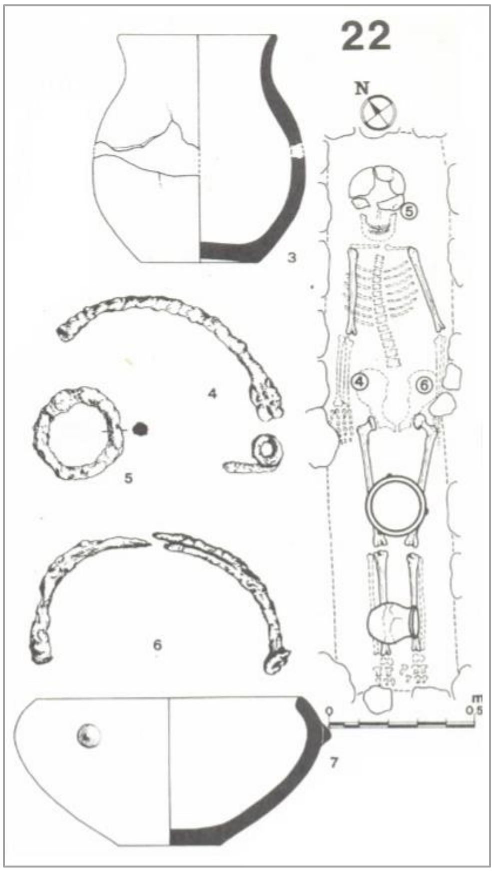

Figure 10.2. Križna gora Grave 22 taken from Urleb et al. (1974: T.5)

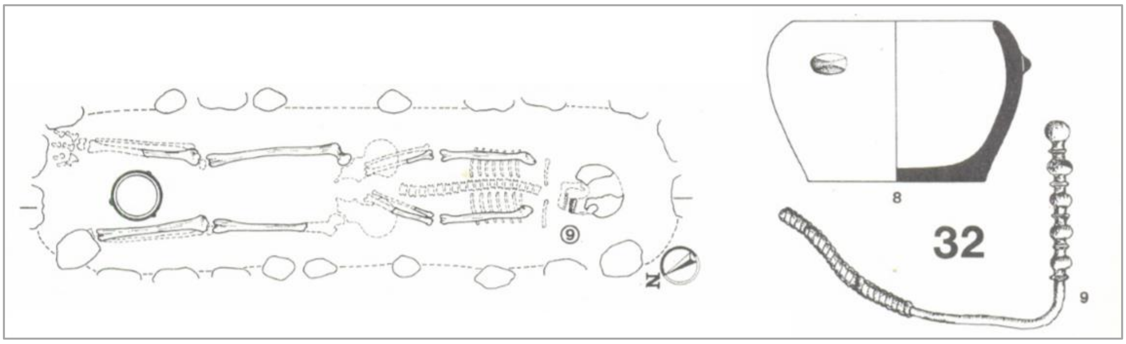

Figure 10.3. Križna gora, Grave 32, taken from Urleb et al. (1974: T.7)

When the oxygen isotope data was considered at the site level, other, tentative, sex-based differences were noted in the oxygen isotope data collected from the enamel of individuals buried at Križna gora. In Section 8.8.2, it was posited that the oxygen isotope ratios from female skeletal remains were more likely to be variable than that from male remains. This could be the result of dietary (weaning ages and durations, or food and beverage types), cultural (differential access to water sources or food or beverage types) or residential factors (movement for marriage, labour or other reasons) (Arnold 1995; Wright and Schwarcz 1998; Brück 2009; Arnold 2012; Lightfoot et al. 2014a; Britton et al. 2015). For the two former possibilities, any differences would have had to have occurred during the formation of tooth enamel and, therefore, during childhood. If the latter possibility were true, with changes in residence being the cause of increased variation within this female group, then this data set could be evidence for increased mobility of women within this community, in comparison to men. However, this is a small and biased data set and, as such, more work would be required to investigate this hypothesis further.

To further explore the potential of oxygen isotope analysis in the East Alpine Region, it would be advantageous to construct an isotopic animal baseline of $\delta^{18}O$ values. Although not directly comparable with human results, the sequential sampling of animal tooth enamel for $\delta^{18}O$ and $\delta^{13}C$ values has previously been carried out as a method of investigating seasonal variability in animal diet (Zazzo et al. 2006) and climate (Stevens et al. 2011). Using this technique, interpretations regarding animal husbandry practices, such as seasonal fodder provision (Balasse et al. 2006; Balasse et al. 2012) and controlled breeding seasons (Balasse and Tresset 2002; Balasse and Tresset 2007; Towers et al. 2011; Towers et al. 2014; Towers et al. 2017).

10.6.2 Strontium isotope analysis

When the pilot data from strontium isotope analysis is considered, some variability was noted in the Dolge njive sample. This linear spread of data points was interpreted as a probable movement of resources or people between two geologically distinct locations (Montgomery et al. 2007; Montgomery 2010). The identification of three siblings following aDNA analysis; two brothers with similar strontium isotope ratios, and one sister with a somewhat different ratio, contributed to the complexity of this data set. This difference in strontium isotope ratios suggests that the brothers spent a significant period before 3.5 years or age (permanent first molar tooth crowns completed by 3.5 years) in a different location to that of their sister, prior to 3.5 years of age. The similarities observed in the carbon and nitrogen isotope data between these siblings and between the remainder of the cemetery group indicated that all of the individuals buried at Dolge njive were consuming a similar diet, with variable millet consumption. Evidence from strontium concentrations, however, highlighted potential dietary differences, with the brothers eating a higher quantity of meat/dairy than their sister. This difference in diet could account for the differences observed in the strontium isotope ratios if these foodstuffs were also originating from different locations.

Evidence from this cemetery group gives an impression of a community within a network, with resources (and perhaps individuals) travelling between two geologically distinctive locations, as indicated by the linear spread in the strontium isotope data. The identification of siblings with dissimilar strontium isotope ratios, being buried together as part of a communal tumulus, also supports this interpretation.

Chapter 11 Conclusions and further work

This work forms the first multi-scalar, multi-disciplinary investigation of human remains dating to the Late Bronze Age/Early Iron Age transition, from Slovenia and north-eastern Croatia. The study has built upon previous work to investigate the themes of homogeneity and heterogeneity of communities inhabiting these areas, to explore their social identity and structure in Later Prehistory. Although the condition of these skeletal remains has been a limiting factor throughout this investigation, this work has shown that the application of analytical and observational methods can provide meaningful results and interpretations, even on remains considered to be of poor quality. The use of numerous methods on the same skeletal assemblages has revealed subtle distinctions that would otherwise have been obscured. This was particularly the case for the carbon and nitrogen stable isotope analyses.

This work has shown that, although these communities initially appear homogeneous in terms of diet and cemetery demography, clear evidence for heterogeneity within and between populations inhabiting this study area has been identified. Throughout this thesis, few definitive conclusions have been drawn, but many possibilities have presented themselves, such as the exploration of variable and complex bodily treatments, especially regarding the analysis of cremated remains, which has provided vital information for the interpretation of past funerary practices. In addition to this, combined methods have highlighted the potential for sex-based dietary and mobility differences, the exceptional focus on millet as a staple cereal, potential variability in animal husbandry practices, good preservation for ancient DNA studies and the construction of more precise chronologies using radiocarbon dating. Furthermore, the pilot investigation using strontium analysis (in combination with oxygen isotope analysis), has shown that more work is required for the creation of baseline data, against which human data can be interpreted with greater certainty. This would be a profitable line of investigation within this study area, to further explore themes of mobility and subsistence strategies.

Overall, this research forms a foundation upon which further work, utilising these and other methods, can be carried out, drawing upon more detailed contextual expertise to explore expressions of identity and social structure across this study area. The application of a multi-scalar methodology, investigating regional trends and individual biographies, has facilitated a greater understanding of life death and diet in later prehistoric Slovenia and north-eastern Croatia. Each osteological, isotopic, and chronological method has provided important evidence alone, which could then be brought together to form more detailed, holistic interpretations. This study, therefore, has shown that the application of each method used independently would greatly add to the current understanding of Late Bronze Age/Early Iron Age society in this area, but also, where possible, interpretations should be made combining evidence from multiple sources.

Potential research trajectories as a result of this study are numerous. In regard to the Stable Isotope analysis, further investigation of dentine increments for carbon and nitrogen stable isotopes would be profitable for investigating variable childhood diet and metabolism. This method, presented in Chapter 6, gave clear evidence for fluctuations in both carbon and nitrogen isotope ratios throughout the development of the dentine. As only the teeth of individuals who died during childhood were sampled as part of the ENTRANS project, it would be interesting to compare these isotope profiles with those obtained from individuals surviving into adulthood (Beaumont et al. 2013a; Beaumont et al. 2013b). From this new data, it would be possible to compare isotope results to assess whether these fluctuations were widespread, or if they were potentially linked to the death of the non-adults already analysed, as was examined in Chapter 7.

In regard to strontium and oxygen Stable Isotope analysis, this investigation has revealed the necessity to build a larger corpus of data to compare populations within the regional landscape of the South Alpine Region and Pannonian Plain. Through the creation of larger data sets, subtle differences and local variations in isotope data may become more visible, allowing for greater and more reliable interpretations regarding mobility and geographical origins during Later Prehistory. Key to this kind of investigation would be an in-depth knowledge of the local geology and hydrology of the areas settled by these communities.

Concerning the osteological analysis of inhumation and cremation graves from the area, it has become clear during this research that, although the preservation of the skeletal material uncovered throughout the ENTRANS study area was generally poor, vital information can still be gained from these skeletal assemblages. For this reason, it is recommended that future investigations into archaeological communities include an osteological aspect. This is true for both the non-cremated and cremated material. The osteological analysis of non-cremated skeletal material has provided evidence of cemetery demographics, trauma and pathological conditions. The analysis of cremated bone gave an insight into the pyre technology, attitudes towards the dead and funerary practices. Further work in regard to cremated remains would include analytical techniques, such as FTIR (Walker et al. 2008; Thompson et al. 2009; Ellingham et al.). This method has been shown to provide more reliable data than the observation of colour, which can be used to infer cremation conditions such as temperature. Unlike the use of colour, this method can be used to produce quantifiable results, which can subsequently be investigated using statistics to test for differences between sites.

Finally, further work to bridge the cultural evidence and the osteological and analytical data is vital for the creation of meaningful interpretations and conclusions. This is scheduled as a number of project led outputs. Members of the ENTRANS project are working to create holistic interpretations, combining the main themes of Art, Landscape and Mortuary Practice. Subsequently, the research contained within this current volume shall be presented in collaboration with other partners with cultural expertise, considering geography, landscape use, objects and art.

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